ASTRONOMY IN INDIA

A PERSPECTIVE

Rajesh Kochhar & Jayant Narlikar

A DIAMOND JUBILEE PUBLICATION

INDIAN NATIONAL SCIENCE ACADEMY
NEW DELHI

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Foreward

Astronomy is the oldest scientific discipline humankind has known. Being an ancient culture, India has a long tradition of astronomical and related activities. As present we have no definite clues to the astronomical knowledge of the Harappan people. Although Rigveda contains stray astronomical references, the oldest Indian text exclusively devoted to the subject is the *Vedanga Jyotisha*, which is generally dated about 1400 BC. This work, mostly attributed to Lagadha, describes a rather inexact calendar in which a five-year yuga is equated with 1830 civil days. (Correct value would be 1826 days plus a fraction.)

Mathematically rigorous, Siddhantic astronomy began in AD 499 with the influential treatise *Aryabhatiya*. Ironically, while today we take great pride in Aryabhata's achievement, in ancient times he was severely condemned by many for deviating from tradition. During the Siddhantic phase, instruments and observations played second fiddle to mathematical calculations. Observational astronomy came to its own in the 14th century when, under the patronage of Ferozshah Tughlaq, Persian and Arabic Zizes (observational tables) were copied, commented upon and to an extent Sanskritized. The Zij phase came to an end with Raja Jai Singh Sawai's imposing but anachronistic pre-telescopic, masonry observatories built at Delhi and Jaipur during 1721-34.

Modern astronomy came to India in tow with the Europeans, who needed it as a navigational and geographical aid. Telescopes were sporadically used in India by the English and the French in the 17th century itself. However, it was in the post-Plassey period that modern astronomy was officially patronized for reasons of state. An observatory was set up at Madras in 1790, to act as India's Greenwich. Along with the botanical garden established at Sibpur near Calcutta in 1787, the observatory was, in today's idiom, the first modern research institute in India.

The 20th century saw the fruition of Indian response to modern science. T.P. Bhaskaran (also known as Bhaskara Sastri) became the first Indian director of Nizamiah Observatory, Hyderabad, in 1922, and A.L. Narayan of Kodaikanal Observatory in 1937. More importantly, Indian universities produced epoch-making work. M.N. Saha's theory of thermal ionization laid the foundation of theoretical astrophysics, whereas N.R. Sen and V.V. Narlikar initiated research into theory of relativity. Astronomical sciences were well represented in the Indian National Science Academy when it was set up in 1935. (It was then known as the National Institute of Sciences of India. The name was changed in 1970.) Its foundation fellows included Saha, Sen, Bhaskara Shastri and A.L. Narayan. Another 'astrophysical' foundation fellow was A.C. Banerji, who later became the vice-chancellor of Allahabad University.

Building an astronomical observatory in the 18th century was one of the first scientific acts of the British in India; establishment of the Indian National Science Academy one of the last. The observatory and the Academy between them neatly bracket the institutionalization of modern science in India under colonial auspices and the consequent emergence of National Science. It is therefore appropriate that on the occasion of its diamond jubilee the Academy should bring out a book dealing primarily with modern astronomy in India.

Astronomy and astrophysics in India have come a long way since independence. A number of astronomical centres have come up that seek to observe the universe in various wavelength bands, from ground and from space. In addition, theoretical studies are being carried out at various places. If the universities have not lived up to their early promise, remedial action is being sought by the establishment of inter-university centres. Indian participation in the worldwide development of astronomy has been steadily growing. This is reflected in research publications, in school, workshop and conference activities and in collaborative research projects between scientists in this country and abroad. Astronomy and astrophysics form an important component of the scientific activities overseen by the Indian National Science Academy.

This small book by Rajesh Kochhar and Jayant Narlikar gives a concise account of modern astronomical facilities in India. This account has been placed in the context of historical developments in India on the one hand and global state of the art on the other. I hope this book will appeal to a wide spectrum of readership.

S.K. Joshi
President
Indian National Science Academy

New Delhi
October 1994

Preface

This book gives a brief account of astronomical research in India. Chapter 1 begins with a resume of pre-telescopic developments and goes on to describe the advent and growth of modern astronomy in India up to the time of independence. Chapter 2 describes the present research facilities at various astronomical centres and their future plans. Chapter 3 describes the highlights of research programmes in India. Chapter 4 is devoted to promotional activities at professional, amateur and popular level.

This book draws heavily on a compilation which we brought out on behalf of our institutions last year *(Astronomy in India:Past, Present and Future)*. Our task has been rendered easier by the co-operation we received from our many colleagues, friends and their institutions. Several of them have contributed by sending relevant material or by reviewing it. We take this opportunity to thank them. We also thank the Chairman and the members of the National Committee for the International Astronomical Union for their helpful suggestions. We thank the Director, Salar Jung Museum, Hyderabad for making available a photograph of a painted sketch of Lilavati and for permitting us to include it in the present work.

Indian Institute of Astrophysics, Bangalore Rajesh Kochhar

Inter-University Centre for Astronomy & Astrophysics, Pune Jayant Narlikar

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Historical perspective

India, as can be expected from an ancient culture, has a long astronomical tradition. The oldest astronomical text in India is the *Vedanga Jyotisha* (astronomy as part of the Vedas), one part of which is attributed to Lagadha. It is dated about 1400 BC on the basis of the statement in the book that the winter solstice took place at the star group Shravishtha (Alpha Delphini). A later astronomer of the same school is Garga who is placed at about 450 BC on the basis of his observation that `the sun is found turning [north] without reaching the Shravishthas'. The earliest interest in astronomy was in observing equinoxes and solstices for ritualistic purposes, in making rather inexact luni-solar calendars, and in observing conspicuous stars (Nakshatras) as a guide to the motion of the moon and the sun.

Siddhantic astronomy

The development of mathematical, or Siddhantic, astronomy came about as a result of interaction with Greece in the post-Alexandrian period. (Siddhanta literally means the established end.) The leading figure in this modernization was Aryabhata I, who was born in AD 476 and completed his influential work, *Aryabhatiya,* in AD 499. The main occupation of Indian astronomers for the next thousand years and more was the calculation of geocentric planetary orbits and developing algorithms for the solution of the mathematical equations that arose in the process. Illustrious names in Indian astronomy following Aryabhata are Latadeva (505) who was Aryabhata's direct pupil; Varahamihira (c. 505) a compiler rather than a researcher, and an expert on omens; Bhaskara I (c. 574); Aryabhata's bête noire Brahmagupta (b. 598) whose works were later translated into Arabic; Lalla (c. 638 or c. 768); Manjula or Munjala (932); Shripati (1039); and Bhaskara II (b. 1114), the last of the celebrated astronomers (Table 1).

There were also a host of commentators including such well-known names as Prithudaka (864) in Kannauj, Bhattotpala (966) in Kashmir, and Parameshvara (1380-1460) in Kerala, who were astronomers in their own right. There were also a number of astronomers whose own work

is not extant, but they are cited by others. There is an Indian astronomer Kanaka who is unknown to Indian sources but appears in the Arabic bibliographic tradition as Kanak al-Hindi. He is said to have been a member of the embassy that was sent from Sind to Baghdad to prepare *Zij al-Sindhind* (translation of Brahmagupta's *Brahma-sphuta-siddhanta*). In the absence of any reliable information on him, a large number of legends have grown around him, making him a personification of the transmission of science from India to the Arabs.

In addition to the Siddhantas there are in Sanskrit and allied languages books called Karanas. If Siddhantas are the text books, Karanas are the made-easy books (Table 2). They give practical rules for carrying out computations. A noteworthy feature is that Karanas choose a contemporaneous epoch rather than follow the Siddhantas in starting from a Kalpa or a Yuga. As early as about AD 1000, Al Biruni (973-1048) noted that there were innumerable Karana works. One of the most influential has been Ganesha Daivajna's *Graha-laghava* (1520). Karana activity continued right up to the 19th century, and was even sponsored by the British. There are tertiary texts also associated with Siddhantas and Karanas. They are the Koshtakas or Saranis, which provided ready-made specialist astronomical tables for use by astrologers and almanac makers.

Work on observational aspects has been rather limited. Parameshvara made eclipse observations from 1393 to 1432, and later Achyuta Pisharati (c.1550-1621), also in Kerala, (c.1730-1800) wrote a four-chapter treatise *Uparagakriyakrama* on lunar and solar eclipses. In the 18th century Nandarama Mishra (c.1730-1800) prepared a Karana work, *Grahana-paddhati,* on eclipses..

The Siddhantic school was mildly influenced by the British presence in India. Indian assistants at British Indian observatories tried to update Siddhantic elements. Kero Lakshman Chhatre (1824-84) started his career at Colaba Observatory in 1851, became the professor of mathematics and natural science at Poona College in 1865, and was made a Rao Bahadur in 1877 two years before his retirement. In 1860 he brought out in Marathi a handbook *Graha-sadhanachi-koshtake*, based on the 1808 work of R.S. Vince. An assistant at Madras Observatory, Chintamani Ragoonatha Charry (1828-80), completed his Tamil work *Jyotisha-chintamani*, and also an almanac, called *Drig-ganita-panchanga*, based on the Nautical Almanac. Many young men from families with tradition of Sanskrit studies took to modern astronomy. A school teacher Venkatesh Bapuji Ketkar (1854-1930) compiled a modern astronomical almanac *Jyotir-ganita* in Sanskrit, with the year 1875 as the epoch. Ketkar is however better known in India for his published prediction (1911) of the existence of a planet beyond Neptune.

It is a matter of historical curiosity that the last of the classical Siddhantic astronomers

Table 1. Important Siddhantas

Year	Author[1]	Place	Work[2]
b.476	Aryabhata I	Patna	Aryabhata-siddhanta Aryabhatiya (499)
c.505	Latadeva		Redactions of Saura-, Romaka-, Paulisha-siddhantas
c.620-700	Brahmagupta*	Bhillamala, Rajasthan	Brahma-sphuta-siddhanta (628)
fl.629	Bhaskara I	Valabhi, Gujarat	Maha-bhaskariya (629) Laghu-bhaskariya
8th cent.	Lalla	Dasapura, Malwa	Shishya-dhi-vriddhida (748)
c.800	Anon.		Surya-siddhanta
b.880	Vateshvara	Vatanagara, N.Gujarat	Vateshvara-siddhanta (904)
c.953	Aryabhata II		Maha-siddhanta
c.1000-1050	Shripati*	Rohinikhand, S.of Ujjain	Siddhanta-shekhara
b.1114	Bhaskara II*	Vijjalavida, Bijapur	Siddhanta-shiromani (1150)
b.1444	Nilakantha Somayaji	Kundapura, Kerala	Tantra-sangraha
c.1475 -1525	Jnanaraja	Parthapura,Godavari	Siddhanta-sundara (1503)
c.1550-1621	Achyuta Pisharati*	Kerala	Sphuta-nirnaya-tantra
c.1600-1660	Nityananda	Kurukshetra	Siddhanta-sindhu (1628) Siddhanta-raja (1639)
b.1603	Munishvara	Varanasi	Siddhanta-sarvabhauma (1646)
b.1610	Kamalakara	Varanasi	Siddhanta-tattva-viveka (1658)
1835-1904	Chandrashekhar Simha	Khandapara, Orissa	Siddhanta - darpana (1894)

1. Asterisk denotes appearance in Table 2 also.
2. The number in bracket after the work is the year of its composition or the epoch chosen for computations.

Table 2. Important Karanas

Year	Author[1]	Place	Work[2]
505	Varahamihira	Ujjain	Pancha-siddhanta
c.620-700	Brahmagupta*	Bhillamala, Rajasthan	Khanda-khadyaka (665)
c.650-700	Haridatta	Kerala	Graha-chara-nibandhana (683)
c.650-700	Devacharya	Kerala	Karana-ratna (689)
c.900 -950	Manjula (or Munjala)	Prakashpattana	Laghu-manasa (932)
c.1000-1050	Shripati*		Dhi-kotida-karana (1039)
c.1050-1110	Brahmadeva	Mathura	Karana-prakasha (1092)
c.1060-1110	Shatananda	Puri,Orissa	Bhasvati-karana (1099)
b.1114	Bhaskara II*	Vijjalavida, Bijapur	Karana-kutuhala (1183)
c.1280-1350	Chakreshvara Mahadeva	Rasina, Godavari	Mahadevi (1316)
13-14th cent.	Vararuchi	Kerala	Vakya-karana (1282/1306)
1367	Mahadeva	Trymbak, Godavari	Kamadhenu-karana
c.1360-1455	Parameshvara	Alattoor, Kerala	Drig-ganita (1430)
1375	Ishvara		Karana-kantirava
1417	Damodara		Bhata-tulya
c.1450-1510	Keshava	Nandgaon, Maharashtra	Graha-kautuka (1496)
c.1475-1550	Chitrabhanu		Karanamrita (1530)
c.1500-1560	Shankara Variyar	Kerala	Karana-sara
b.1507	Ganesha Daivajna	Nandgaon, Maharashtra	Graha-laghava (1520)
c.1540-1600	Dinakara		Kheta-siddhi (1578) Chandrarki (1578)
c.1550-1621	Achyuta Pisharti*	Kundapura, Kerala	Karanottama (1593)
c.1500 -1620	Ramachandra Bhata	Delhi	Rama-vinoda (1590)
c.1550 -1620	Vishnu	Golagram, Godavari	Suryapaksha-sharana-karana (1608)
c.1589	Dhundhiraja	Parthapura, Godavari	Graha-mani
c.1590-1650	Nagesha	Gujarat	Graha-prabodha (1619)

Year	Author[1]	Place	Work
c.1600-1660	Krishna	Konkana	Karana-kaustubha (1653)
c.1650-1720	Jatadhara	Sarhind, Punjab	Phatteshaha-prakasha (1704)
c.1660-1740	Putumana Somayaji	Shivapura, Kerala	Karana-paddhati
c.1730-1800	Nandarama Mishra	Kamyaka-vana	Grahana-paddhati (1763)
c.1740-1800	Shankara	Dvarka, Gujarat	Karana-vaishnava (1760)
c.1750-1800	Manirama		Graha-ganita-chintamani (1714)
c.1781	Bhula	Narmada	Brahma-siddhanta-sara
c.1800-1839	Shankara Varma	Katattanadu, Kerala	Sad-ratna-mala (1823)
c.1800-1850	Jyotiraj	Nepal	Jyotiraja-karana (1832)

1. Asterisk denotes appearance in Table 1 also.
2. The number in bracket after the work is the year of its composition or the epoch chosen for computations.

lived right into the present century. Samanta Chandrasekhara Simha (1835-1904) was born in a princely family in the small village of Khandapara in western Orissa. Introduced to the ancient Siddhantic literature in the family library, he soon noticed that the predictions did not match observations. Following instructions in the old texts, he made his own instruments. His main instrument was a tangent-staff, made out of two wooden rods joined together in the shape of a T. ' The shorter rod was notched and pierced with holes at distances equal to the tangents of angles formed at the free extremity of the other rod '. Calling it *Mana-yantra* (measuring instrument) he used it with a precision which was more due to his innate abilities rather than the instrument's. Using Bhaskara II as his role model he then set out in 1894 to write on palm leaf his *Siddhanta-darpana*, consisting of 2284 shlokas of his own composition to which were added another 216 called from old Siddhantas, especially Bhaskara II's *Siddhanta-shiromani* and *Surya-siddhanta.*

Throughout the Siddhantic period instruments and observations played second fiddle to computations. Observational results were not explicitly recorded, the description of astronomical instruments was condensed in a single chapter, *Yantra-adhyaya.* Although Bhaskara II is credited with devising a rather versatile instrument, *phalaka-yantra*, there is no gainsaying the fact that observational astronomy came to its own only in the medieval times thanks to India's interaction with central and west Asia.

Zij astronomy

This phase of post-Siddhantic world astronomy may be called *Zij astronomy*, because the main occupation of its astronomers was the preparation of Zijes that is astronomical tables. Zijes fall into three categories: (i) *Zij-e-Rashadi* (direct tables) based on actual observations; (ii) *Zij-e-Hisabi* (calculated tables) obtained by correcting observational tables for errors, precession, etc; and (iii) *Zij-e-Tas'hil* (simplified tables) which were simplified versions of other tables, for example, for the moon alone. The Zij period began in the 9th century at Baghdad with the translation of Brahmagupta's Sanskrit works into Arabic, and essentially came to an end in India, with the compilation of *Zij-e-Muhammad Shahi* in 1728 by Raja Jai Singh Sawai. Siddhantic and Zij astronomies flourished simultaneously.

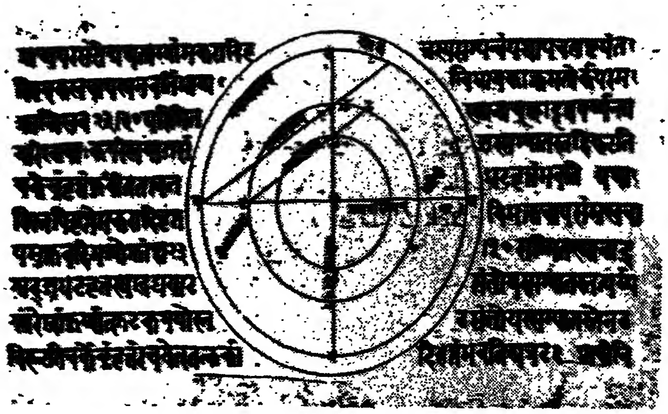
Zij astronomy made its debut in India under the patronage of King Ferozshah Tughlaq who ruled at Delhi from 1351 to 1388. Arabic and Persian Zijes were copied and commented upon. Several books on astronomy were written during his reign, and astrolabes constructed. On his orders, an astrolabe was placed on the highest tower in his capital Ferozabad (in Delhi). In addition, Ferozshah also took steps to Sanskritize instrumentation astronomy. On his orders, Mahendra Suri, head astronomer at the royal court, prepared in 1370 *Yantra-raja*, a monograph on astrolabe. This was the first Sanskrit work exclusively devoted to instrumentation, and was the subject of many later commentaries. Table 3 lists Sanskrit texts exclusively devoted to astronomical instruments.

From 18th century, we have Raja Jai Singh Sawai's treatise on instruments, *Yantra-prakara*, essentially completed before 1724, with some additions made up to 1729. In 1732, his astronomer Jagannatha translated Nasir al Din al Tusi's (1201-74) Arabic recension of Ptolemy's Almagest into Sanskrit under the title *Samrata-siddhanta*, To it, he added a supplement describing various instruments. Jai Singh went on to establish a number of (pre-telescopic) masonry observatories. The Delhi Observatory set up during 1721-24 was followed by a bigger one at his new capital Jaipur (1728-34). He built smaller ones at Mathura, Ujjain and Varanasi between 1723 and 1734. (All dates are estimates.) The Varanasi Observatory was housed in an already existing building; it is probable that Jai Singh renovated an old observatory. Jai Singh's instruments and observations have been extensively dealt with in the literature.

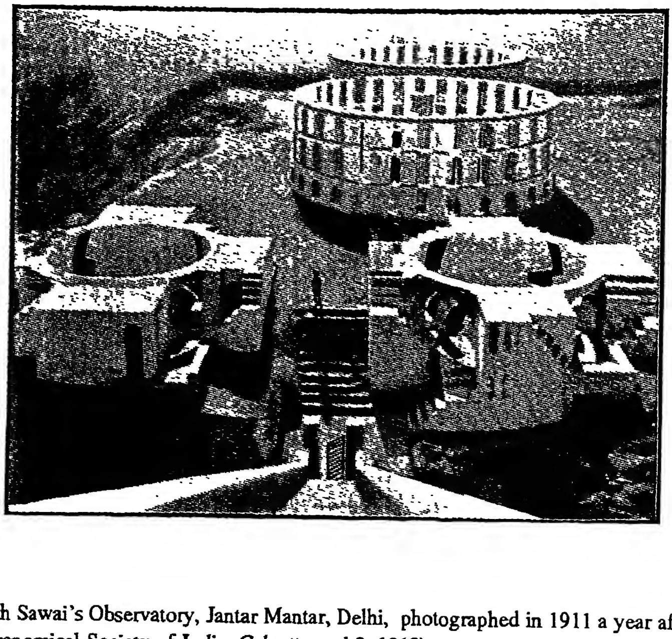
Jai Singh's edifice of science did not survive for long. In 1745, two years after Jai Singh's death, Emperor Muhammad Shah invited Father Andre Strobel to come to Delhi and take charge of the Observatory. He declined. In 1764 the Observatory was severely vandalized, when Javahar Singh, son of Suraj Mal, the Jat Raja of Bharatpur, plundered Delhi. More than 150 years later,

Table 3. Instrumentation texts in Sanskrit

Year	Author (Place)	Work	Instrument
1370	Mahendra Suri (Delhi)	Yantraraja	Astrolabe
c.1400	Padmanabha	Yantra-kiranavali	Astrolabe Dhruva-bhramana-yantra
1428	Ramachandra (Sitapur, U.P.)	Yantra-prakasha	Misc.
15th cent.	Hema (Gujarat)	Kasha-yantra	Cylindrical sundial
b.1507	Ganesha Daivajna	Pratoda-yantra	Cylindrical sundial
		Sudhiranjana-yantra	Graduated strip
c.1550-1650	Chakradhara (Godavari)	Yantra-chintamani	Quadrant
1572	Bhudhara (Kampilya)	Turiya-yantra-prakasha	Quadrant
c.1580-1640	Jambusara Vishrama (Gujarat)	Yantra-shiromani (1615)	Misc.
fl.1720	Dadabhai Bhatta	Turiya-yantrotpatti	Based on Chakradhara's work
1688-1743	Jai Singh Sawai (Jaipur)	Yantra-prakara Yantra-rajarachana	Misc. Astrolabe
c.1690-1750	Jagannatha (Jaipur)	Samrata-siddhanta (1732)	Tr. of Almagest with suppl. on instruments
c.1700-1760	Lakshmipati	Dhruva-bhramana-yantra Samrata-yantra	
c.1700-	Nayansukha Upadhyaya	Yantra-raja-risala-bisa-baba or Yantra-raja-vichara-vimshadhyay	Astrolabe (Tr. of MS by Nasir al Din al Tusi, 13th cent., Iran)
c.1750-1810	Nandarama Mishra (Kamyakavana, Rajasthan)	Yantra-sara (1772)	Misc.
c.1750-1810	Mathuranatha Shukla (Varanasi)	Yantra-raja-ghatana (1782)	Astrolabe
c.1736-1811	Chintamani Dikshit	Golananda (1800)	Misc.



1. A page from the Sanskrit manuscript *Yantra-raja-kalpa* (1782) by Mathuranatha, describing the construction of an astrolabe. The manuscript, copied in 1820, is at Sampurnanand Sanskrit University, Varanasi (S.R.Sarma).



2. Raja Jai Singh Sawai's Observatory, Jantar Mantar, Delhi, photographed in 1911 a year after its renovation (Journal of Astronomical Society of India, Calcutta, vol.2, 1912).

the then Maharaja of Jaipur perfunctorily renovated the Observatory to give it a presentable look at the time of the 1911 Delhi darbar of King George V. (The Delhi and Jaipur Observatories are now in a rather dilapidated state and no more than popular tourist spots.

Perhaps the most telling commentary on Jai Singh's dedicated but largely irrelevant scientific enterprise comes from the rather disconcerting fact that his grandson converted Jaipur Observatory into a gun factory and used his ancestral 400 kg astrolabe for target practice.

Advent of modern astronomy

Modern astronomy came to India in tow with the Europeans. The earliest recorded use of telescope in India was rather atypical; it was in the field of pure astronomy rather than applied. The observer was an Englishman, Jeremiah Shakerley (1626-c.1655). He was one of the earliest followers of Kepler and viewed the 1651 transit of Mercury from Surat in west India. He could however time neither the ingress nor the egress. His observation therefore was of no scientific use and remains a curiosity. More representative of the things to come was the work of the Jesuit priest Father Jean Richaud (1633-93) who in 1689 discovered from Pondicherry that the bright star Alpha Centauri is in fact double.

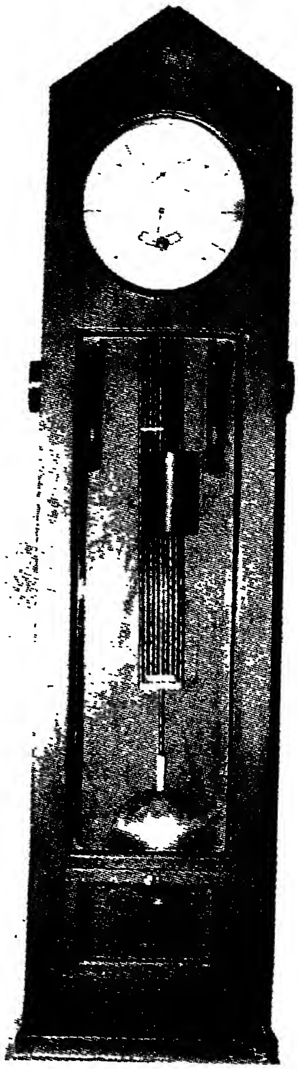
Early use of telescopic astronomy by the Europeans as a geographical aid in India was desultory, sporadic and often motivated by personal curiosity. The 1761 and 1769 transits of Venus were perceived as a continuation of the ongoing rivalry between France and England, and brought many instruments and a general awareness of astronomy to colonial India. What however led to the institutionalization of modern astronomy in India was not the love of stars, but rather the fear of the Coromandel coast. Rocky and full of shoals, and devastated by two monsoons a year, India's east coast became the graveyard of many a sailing ship. Its survey literally became a matter of life and death for the British. Accordingly, a well-equipped, trained surveyor - astronomer Michael Topping (1747-96) was brought to Madras in 1785.

Madras Observatory (1786)

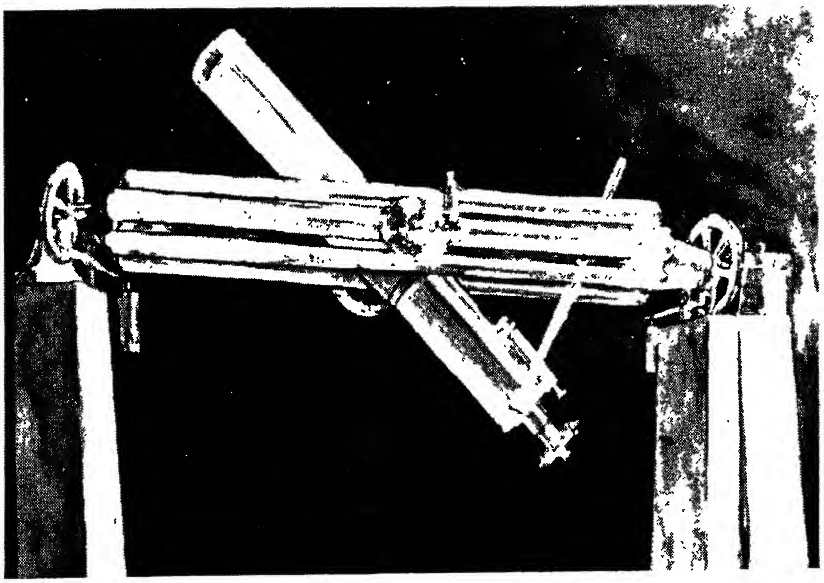
Next year, perhaps more by design than chance, there came up at Egmore in Madras a small private observatory. Its founder was William Petrie (d.1816), an enlightened and influential

company officer, who later officiated as the governor of Madras for a few months. It was used by Topping as a reference meridian and on Petrie's persuasion was taken over by the company in 1790. Two years later the Observatory moved to its own campus at Nungambakkam in Madras, where some of its old remnants can still be seen. A hundred years later, in 1899, astronomical activity was shifted to Kodaikanal, and the Madras Observatory became a purely meteorological observatory. One of the instruments that Petrie bequeathed to the Observatory was a pendulum clock by John Shelton. Believed to be made for the 1769 transit of Venus and identical to the one used by Captain James Cook in his voyages, it is still ticking at Kodaikanal, a witness to the advent and growth of modern astronomy in India.

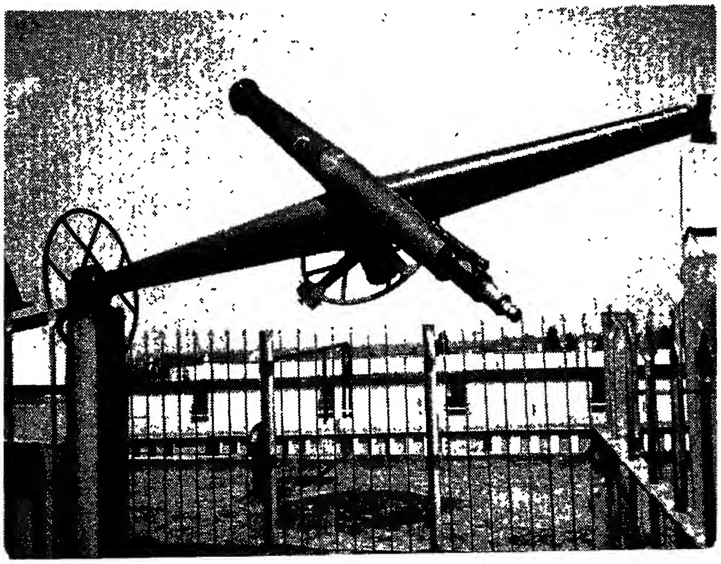
In the early years Madras Observatory not only provided the reference meridian for the work of the Great Trigonometrical Survey of India (GTS) but also manpower and instruments. Increasing overseas involvement of Britain required familiarity with the southern skies. Accordingly, in 1843, after 13 years of painstaking work with the newly acquired transit instrument and mural quadrant (both by Dollond and with 4 inch aperture telescopes), Thomas Glanville Taylor (1804–48), former assistant at Greenwich, produced the celebrated Madras Catalogue of about 11000 southern stars. It was hailed by the Astronomer Royal Sir George Biddell Airy as 'the greatest catalogue of modern times'. (It was revised in 1901.)



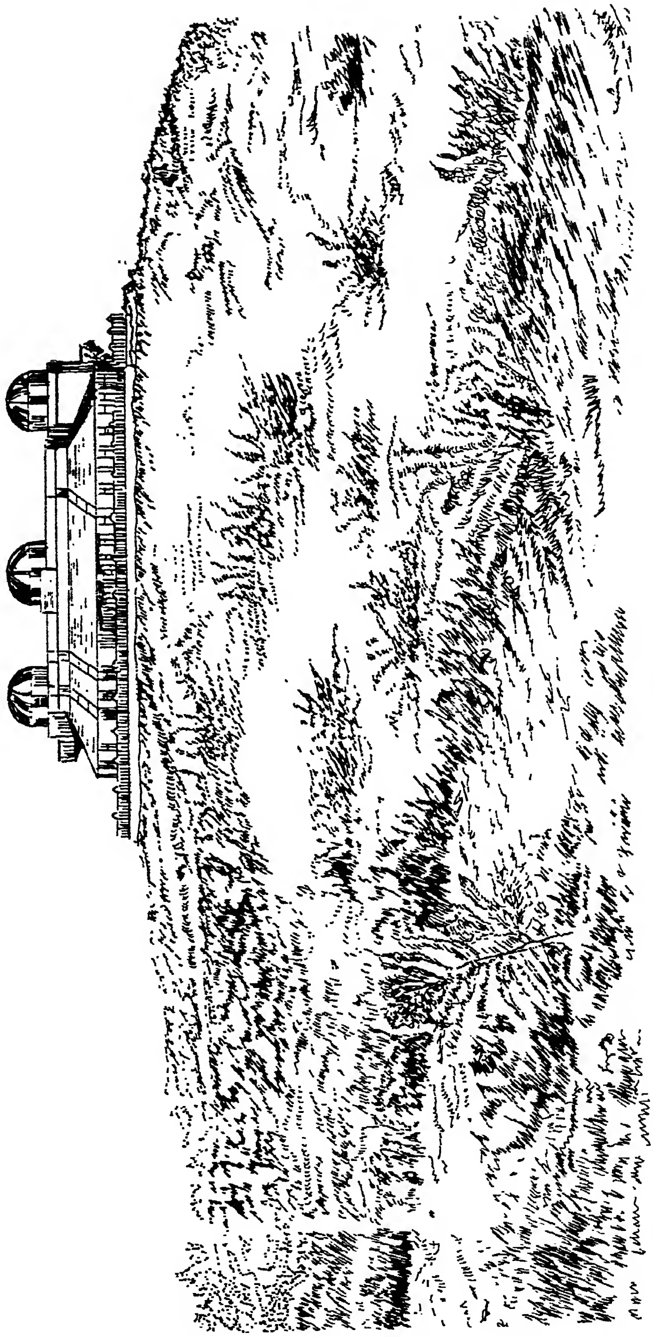
3. Gridiron pendulum clock by John Shelton. Identical to the one used by Captain Cook in his famous voyages, and to the one used by Charles Mason and Jeremiah Dixon in N. America to determine the Mason-Dixon Line, this Shelton was a part of the original equipment of the Observatory set up by William Petrie at Madras in 1786. The clock has been at Kodaikanal since 1899, and is still ticking.



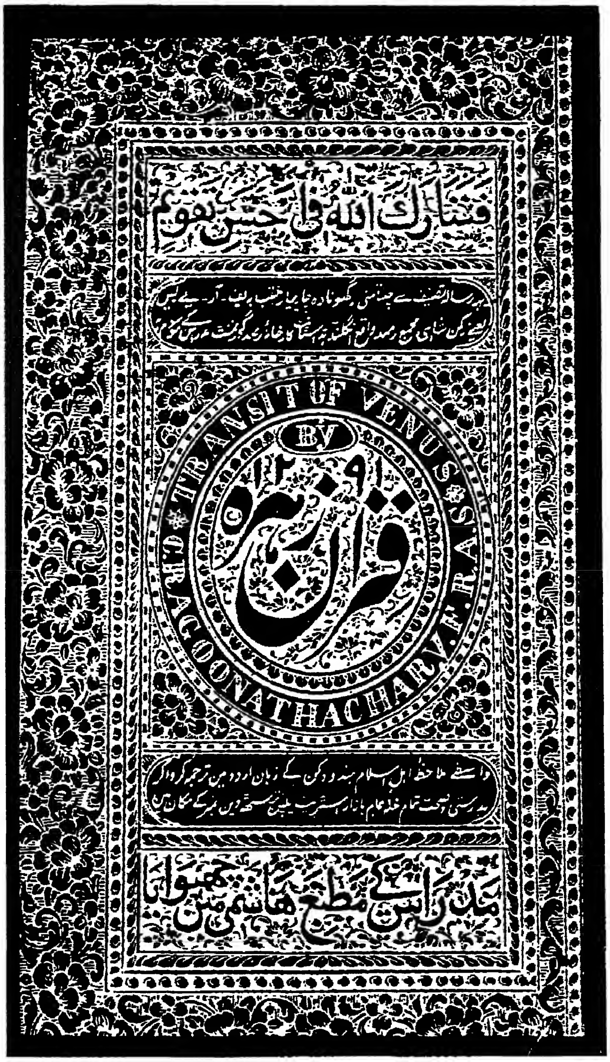
4. Six inch aperture lens telescope on English mounting, by Lerebours & Secretan of Paris. Sketched in colour by Charles Piazzi Smyth in 1851. (The original is at the Royal Observatory, Edinburgh.) The telescope was ordered for Madras Observatory. Since modified, it is now at Kodaikanal.



5. Five inch aperture, 7 foot focus, lens telescope on English mounting by Dollond, it was acquired by Trivandrum Observatory in 1842.



6. A (retouched) sketch of Trivandrum Observatory (Madras Journal of Literature & Science, vol. 6, 1837).



7. The title page of a booklet in Urdu brought out by Chintamani Ragoonathachary on the occasion of the 1874 transit of Venus. (His names is spelt variously). He was an assistant at Madras Observatory, and is the discoverer of a variable star R Reticuli.

In 1850, the Observatory acquired its first fixed extra-meridional instrument, a 6 inch aperture lens telescope by Lerebours & Secretan of Paris. It was used by Captain William Stephan Jacob (1813-62) to show that the recently discovered crepe ring of Saturn was in fact translucent. (The same discovery was independently made a little later by William Lassel at Malta using a 20 inch reflector.) The only other telescope at Madras, an 8 inch lens equatorial by Troughton & Simms, was ordered in 1861. (Both these telescopes are now at Kodaikanal.)

The Madras Observatory had already become redundant as far as utilitarian astronomy was concerned. And when observatories came up in South Africa and Australia, even the British astronomers lost interest. Norman Robert Pogson's (1829-91) 30 years' uninterrupted stint from 1861 till his death is a tragic testimony to the wasted opportunities at Madras. He was the first astronomer at Madras who did not have any surveying connection. His own neurosis was matched by the Astronomer Royal's imperiousness. Left to himself Pogson would have liked to extend Argelander's survey to the southern skies and work on his variable star atlas. Instead, he was forced to carry on routine, drab, irrelevant observations of transits year after year, which he most obstinately refused to reduce and publish. No new instruments were ordered during Pogson's long tenure. What kept the Observatory in working order was the help given by the workshops established by the government's public works department for its own use.

Watching the GTS and the Madras Observatory at work, two native rulers came forward to extend patronage to modern astronomy. It is not that they strove to update the elements of traditional astronomy in the light of new developments in the west or wanted their subjects to learn new astronomy. Instead, they simply funded British efforts. When the Nawab of Oudh (correctly Avadh, eastern Uttar Pradesh) decided in 1831 to set up an observatory he asked the governor general to send one of his GTS officers (Major James Dowling Herbert 1791-1833) as the director. As befit a Nawab's whim, Lucknow Observatory was equipped with the best instruments money could buy, but closed down as soon as the novelty and the instruments wore off. The Observatory was abolished in 1849, and ransacked in 1857. In the meantime all the records of the Observatory, reduced as well as unreduced, were eaten by ants. Thus ended a first class, though unproductive, observatory which need not have been set up in the first place. Circumstances attending the Trivandrum Observatory were slightly different. Here the initiative came from the British men of science, whom the King gladly obliged. The Observatory was established in 1837 with John Caldecott (1813-47) as the astronomer. Astronomy met the same fate as at Lucknow. But thanks to Trivandrum's proximity to the magnetic equator and to Madras presidency, the Observatory could do sustained work in the fields of magnetism and meteorology under John Allan Broun (1817 - 79), on the lines suggested by the British Association for the Advancement of Science.

Advent of physical astronomy

While positional astronomy was slugging it out at Madras, there was taking shape in Europe the new science of physical astronomy or astrophysics. Spectroscopic and photographic techniques were used in the Indian observations of the solar eclipses of 1868, 1871 and 1872, which attracted observers from Europe also. The French astrophysicist Pierre Jules Cesar Janssen (1824-1907) observing the total solar eclipse of 1868 from Guntur (now in Andhra Pradesh) detected a spectral line due to a new element, aptly named helium by the independent co-discoverer Joseph Norman Lockyer (1836-1920). During his post-eclipse stay at Simla, Janssen created the first spectrohelioscope, which facilitated daily examination of the sun. It was the transit of Venus of 9 December 1874 that led to institutionalization of astrophysics in India. This time the state had no major stake in the new astronomy. The initiative and the pressure came from the European solar physicists who wanted the benefit of India's sunny days for their research. The government was interested in the work as it was told that a study of the sun would help predict the failure of monsoons, then as now India's life-line.

Dehra Dun Observatory (1878-1925)

When India-based Col. James Francis Tennant (later Lieut. - Gen. and President of the Royal Astronomical Society) requested the government for setting up a solar physics observatory with the instruments already in India for the 1874 transit, he was turned down. The government was however more responsive when Lockyer used his equation with Lord Salisbury, the secretary of state for India. Salisbury wrote to the viceroy on 28 September 1877: `Having considered the suggestions made by Mr.Lockyer, and viewing that a study of the conditions of the sun's disc in relation to terrestrial phenomenon has become an important part of physical investigation, I have thought it desirable to assent to the employment for a limited period of a person qualified to obtain photographs of the sun's disc by the aid of the instrument now in India [for transit of Venus observation]'. Accordingly, starting from early 1878 solar photographs were regularly taken at Dehra Dun under the auspices of Survey of India, and sent to England every week. Dehra Dun continued solar photography till 1925, but more out of a sense of duty than enthusiasm. The larger of the two photoheliographs fell into disuse, and in 1898 Lockyer was stung by on-the-spot discovery that `the dome has been taken possession of by bees'.

St Xavier's College Observatory, Calcutta (1879)

Sunny India caught the attention of astronomers in the continent also. The Italian transit-of-Venus team led by Professor P.Tacchini of Palermo Observatory stationed itself in Bengal, its

chief instrument being the spectroscope, `an instrument not recognized in the equipment of any of the English parties'. A co-opted member of the Italian team was the Belgian Jesuit Father Eugene Lafont (1837-1908) professor of science at St Xavier's College, Calcutta, who though no researcher himself was an inspiring educator and science communicator. The College provided education to sons of Europeans, Anglo-Indians, rajas, zamindars, and Indian men of note. Lafont therefore `secured great influence among these classes' which he put to good use in the service of science. Tacchini suggested to Lafont `the advisability of erecting a Solar Observatory in Calcutta, in order to supplement the Observations made in Europe, by filling up the gaps caused in the series of solar records by bad weather'. Lafont soon collected a sum of Rs 21000 through donations, including Rs 7000 from the Lieut.-Governor of Bengal, `and in a couple of years the present spacious dome was constructed and fitted with a splendid 9" Refractor by Steinhill of Munich to which was adapted a large reversible Spectroscope by Browning'. St Xavier's College Observatory did painstaking if not very striking work, thanks to the customary thoroughness and dedication of the Jesuit men of science. At about the same time there came up at Poona a research observatory for entirely different reasons.

Takhtasingji Observatory, Poona (1888-1912)

This was the most personalized of all observatories. In spite of its name, it was owned by the Bombay government and was set up for one man, Kavasji Dadabhai Naegamvala (1857-1938). Naegamvala was a brilliant student. In January 1878, he passed his M.A. examination in physics and chemistry in first class from Elphinstone College, Bombay, and was awarded the chancellor's gold medal, the highest honour of the Bombay University. He returned to the College in 1882 to fill the newly created post of lecturer in experimental physics at a salary of Rs 250 p.m. When the Maharaja of Bhavnagar visited Elphinstone College in October 1882, Naegamvala represented to him for a donation so that a spectroscopic laboratory could be started at the college.

The government matched the royal gift of Rs 5000 with an equivalent grant and sent Naegamvala to England to finalize the equipment `in consultation with the Committee on Solar Physics and best makers of spectroscopic apparatus'. While in England Naegamvala boldly jettisoned laboratory spectroscopy in favour of the celestial. 'By advice of the Astronomer Royal, he allotted the bulk of the funds at his disposal to the purchase of a Reflector Telescope which would be the largest in India'. (This 20 inch Grubb telescope remained the largest in India for eight decades, even if half its time was spent in the boxes). In view of the better credentials of Poona as an astronomical site, the Observatory and Naegamvala were transferred in 1888 to

REGISTERED No. B.661

હિંદી-ગ્રાફીક

THE LATE PROFESSOR KAWASJI DADABHOY NAEGAMWALLA,
M.A., F.R.A.S., etc.

A renowned and foremost Parsee Astro-Physicist, Scientist and Educationist that the community has produced. He was a well-known research scholar in solar spectroscopic work and an author in original scientific research work which has found high recognition in India, England and America.

આદેશ પારસી વિજ્ઞાનશાસ્ત્રી મરહુમ પ્રો૦ કાવસજી દાદાભાઈ નાયગામવાલા,
એમ. એ., એફ. આર. એ. એસ.

વિજ્ઞાન-વિદ્યા મુખ્યથી શોધખોળ કરનારા એક પ્રખ્યાત સ્કોલર તરીકે પ્રો૦ નાયગામવાલા હિંદુસ્તાન ઉપરાંત ઇંગ્લાંડ અને અમેરીકામાં જાણીતા હતા. છેલ્લાં ૩૦ વર્ષોથી મુંબઈ યુનીવર્સીટીમાં સાયન્સના પરિક્ષક નિમાતા હતા અને સીન્ડીક અને ફેલો હતા.

8. Cover page of the April 1939 issue of the Gujarati-English magazine *Hindi Graphic* (Bombay) paying tribute to K.D.Naegamvala: 'A renowned and foremost Parsee Astro-Physicist,Scientist and Educationist that the community has produced'.

the College of Science (now College of Engineering) there. Naegamvala was a member of the British scientific team that went to Norway in 1896 to observe the total solar eclipse. For the 1898 eclipse that was visible from India, Naegamvala was given a sum of Rs 5000 by the government to match an equivalent sum raised through donations, ranging from Rs 100 to Rs 500. (Jamsetji Nusserwanji Tata contributed Rs 250.) The eclipse brought Sir Norman Lockyer and the Astronomer Royal, Sir W.H.M.Christie, to India who were asked by the Government of India to report on the observatories here.

The best thing that could have happened to Naegamvala was his discovery by Lockyer. Lockyer in his report paid glowing tributes to Naegamvala `who, so far as I know, is the only person in India practically familiar with solar physics work'. On Lockyer's recommendation, Naegamvala was relieved of teaching duties and appointed full-time director of the Observatory. He was asked to send data regularly to Lockyer. If Lockyer had had his way, he would have appointed Naegamvala as the director of the proposed Solar Physics Observatory at Kodaikanal in place of the Madras Astronomer Charles Michie Smith about whose capabilities Lockyer had a very low opinion. Naegamvala did not go to Kodaikanal, but in 1912 all his equipment was sent there, when the Poona Observatory was closed down on his retirement.

Kodaikanal Observatory (1899)

Although the question of upgrading the astronomical facilities at Madras had been brought up off and on in the British quarters, it was only after the death of Pogson in 1891 that the matter was taken up in earnest. It was finally decided in 1893 to establish a solar physics observatory at Kodaikanal in the Palani hills of south India with Michie Smith as the director. All astronomical activity was shifted from Madras to Kodaikanal, and the new observatory was transferred from Madras government to the charge of the imperial government's India Meteorological Department.

To start the Observatory, Greenwich sent (on permanent loan) a photoheliograph, one of the five identical ones made by John Henry Dallmeyer for the 1874 transit-of-Venus expeditions. The 6 inch refracting telescope by Lerebours and Secretan of the 1850 vintage was remodelled and installed for daily photography of the sun. (This must be one of the oldest telescopes still in scientific use.) The arrival of John Evershed in 1907 (as assistant director to begin with) heralded the Observatory's golden age. Choosing to come to India, no doubt to work in solitary splendour, Evershed made Kodaikanal into a world-class, state-of-the art observatory. He put the newly acquired spectroheliograph into working order, made a prismatic camera using the prisms

he had brought with him, and assembled a number of spectrographs. In 1911 he finally constructed an auxillary spectroheliograph and bolted it to the existing instrument so that now the sun could be photographed not only in the light of calcium K spectral line but also in hydrogen alpha. In 1909, Evershed made the important discovery of radial flow of gases in sunspots (the Evershed effect). After Evershed's retirement in 1923, the Observatory slowly fell behind times, and became routine-work oriented. It assiduously took solar pictures every day (weather permitting) and exchanged them with other observatories the world over, building in the process an enviable collection of solar pictures that now spans eight complete solar cycles.

Nizamiah Observatory (1901)

The positional astronomy slot that fell vacant in 1899 with the winding up of the Madras Observatory was filled by the Nizamiah (Nizam's) Observatory at Hyderabad. Its founder was a rich England-educated nobleman, Nawab Zafar Jung. The Nawab purchased a small telescope and set up an Observatory at his estate at Phisalbanda in Hyderabad. Very far-sightedly, in 1901, he took the Nizam's permission to name the Observatory the Nizamiah and made sure that it would be taken over by the government on his own death. He subsequently acquired a 15 inch aperture Grubb refractor. Curiously, he also obtained an 8 inch aperture astronomical camera, or astrograph, which later became the Observatory's chief instrument. Zafar Jung died in 1907 and as planned his Observatory was taken over by the government. Thus ironically the formal establishment of the Observatory had to await the founder's death.

The next year the Observatory was formally inducted into an ambitious, on-going, international programme, called Carte-du-Ciel, or astrographic chart and catalogue. The aim of this programme was to photographically map the whole sky by assigning various celestial zones to 18 different observatories around the world. The Nizamiah was asked to take over from Santiago Observatory in Chile, which had defaulted on the (17° to 23° S) zone assigned to it. Finally the Observatory also ended up doing the Potsdam zone 36° to 39° N. In the meantime (March 1908) Arthur Brunel Chatwood, B.Sc., had been brought from England as the director on a monthly salary of Rs 1000 (about £ 1200 a year). Chatwood's tenure was far from a success. He did not go beyond the installation of the astrograph at the new site of Begumpet, and quit in 1914, unlamented.

Astrographic work could be taken up in earnest only in 1914 with the arrival of Robert John Pocock (1889-1918). Pocock was the protege of the influential Oxford professor Herbert Hall Turner(1861-1930) and came 'direct from Oxford', armed with a special grant. The first usable plate was taken on 9 December 1914, and the first volume of results published in 1917.

When the work finally ended in 1946, a total of 7,63,542 stars had been observed, and 12 volumes published. These data were in turn used by the Observatory astronomers to extract information on proper motion of stars and on double stars.

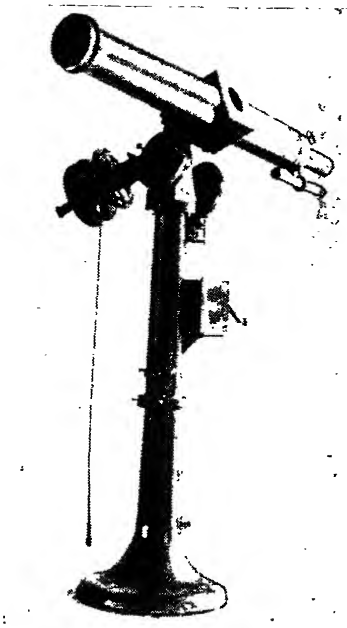
Pocock was the last European director of the Observatory. On his untimely death in 1918 he was succeeded by his erstwhile assistant [Rao Sahib] Theralandoor Panchapagesha Bhaskaran (1889-1950), who however had to wait for four years before getting the formal appointment. Bhaskaran was a foundation fellow of the Indian National Science Academy (INSA) established in 1935 under the name National Institute of Sciences of India (The name was changed in 1970.) In the Academy records his name appears as T.P. Bhaskara Shastri.

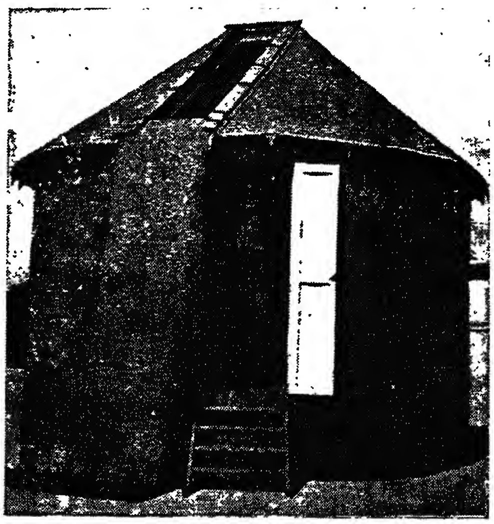
9. The 8 inch Cooke astrograph of the Nizamiah Observatory, used in the Carte-du-Ciel programme 1914-46.

Apart from the astrographic work, Nizamiah had other smaller irons in the fire. The 15 inch Grubb refractor was at long last installed in 1922 and used for visual observations of variable stars as well as of lunar occultations. The sun also received some attention, thanks to a Hale spectrohelioscope acquired in 1939. The Observatory also did some community service. It kept standard time and prepared government calendars in Urdu and English.

Indian response

Just as the British needed (modern) science in India, they needed Indians also. Accordingly, the 'natives' were introduced to English education. As the scientific content of the administration increased, the natives graduated from being clerks and writers to becoming doctors and engineers, and finally scientists. In January 1876, Dr Mahendra Lal Sircar, in collaboration with Fr. Lafont, generated support among Indians as well as in government circles for setting up at Calcutta the rather oddly named Indian Association for the Cultivation of Science (IACS). It was the scientific wing of the Indian Association, which was a political organization





10. Seven inch aperture lens telescope by Merz-Browning at the Indian Association for the Cultivation of Science, Calcutta. It was extensively used by C. V. Raman. The Observatory building is to the right (Report of IACS FOR 1913)

of educated Indians and a precursor of the Indian National Congress.Its aim was to enable the 'Natives of India to cultivate Science in all its departments with a view to its advancement by original research'. A rich benefactor (Kumar Kanti Chandra Singh Bahadur) presented IACS with a valuable 7 inch aperture Merz-Browning equatorial telescope in 1880. It however had to wait for more than 30 years to find a user. Observational astronomy simply failed to take off under Indian auspices.

Appearance of comet Halley in 1910 activated astronomy buffs at Calcutta, who set up an Astronomical Society of India. There were 192 original members including not only men of science but also informed laypersons and Christian missionaries. In addition, there were some rich Indian patrons. The first President was Bengal's accountant general Herbert Gerald Tomkins (1869-1934), who remained the Society's driving force during its decade-long existence. It is not clear whether the Society was formally wound up or simply became defunct. The last available issue of the Society's *Journal* is dated June 1920. (The name of the Society was reused 53 years later while setting up a new Society at Hyderabad in 1973.)

An active member of the Society was Chandrasekhar Venkata Raman (1888-1970), the young deputy accountant general and part-time researcher at IACS who quit his lucrative

government job to take up the newly created Palit professorship of physics at Calcutta University. He served the Society variously as its business secretary, librarian, and director of the variable star section, and contributed to the *Journal* as well as to the discussions. He installed the 7 inch telescope of the IACS and put it to use. Raman maintained a life-long interest in, and enthusiasm for, astronomy. Another member of the Society was a subjudge, Nagendra Nath Dhar (1857-1929), who made optics for telescopes at his workshop at Hooghly and discussed his techniques at the Society meetings.

The most dedicated observer of the time worked outside the pale of the astronomical society. Born in a zamindar family at a small village Bagchar in Jessore district (now in Bangladesh) Radha Gobinda Chandra (1878-1975) left school after failing three times in matriculation examination and took up a job as a *poddar* (coin tester) at the collectorate at a salary of Rs15 monthly. His introduction to astronomy came from a Bengali text and practical acquaintance with the sky from his scientific apprenticeship to a lawyer (Kalinath Mukherjee) who was editing a star atlas. He observed comet Halley through binoculars and in 1912 purchased a 3 inch lens telescope from London for 13 pounds. He became a regular observer of variable stars and a member of the American Association of Variable Star Observers (AAVSO), which in 1926 gave him a 6 inch aperture telescope, originally belonging to AAVSO's `patron and friend' Charles W. Elmer. Chandra certainly made good use of it, communicating a total of 37215 trained-eye observations up to 1954, when he finally retired from observing. The value of his prodigious work lies in the fact that he worked `at a longitude far from that of most observers, greatly improving the temporal completeness of the observational records for the stars he observed'. Chandra was asked to pass on the AAVSO telescope to Manali Kallat Vainu Bappu (1927-82) then at Naini Tal. The Elmer-Chandra telescope, one of the very few American telescopes in British India (if not the only one), is now at Kavalur.

A rather atypical scientific enterprise in the 19th century British India was a private astronomical and meteorological observatory at Daba Gardens. Vizagapatnam (Vishakhapatnam, now Andhra Pradesh). It was established in 1841 at his residence by a rich zamindar Gode Venkata Juggarow (1819-56), who had earlier gone to Madras to take tuition from the astronomer Thomas Glanville Taylor. On Juggarow's death the zamindari and the Observatory passed on to his son-in-law Ankitam Venkata Nursing Row (1827-92) who resigned his job as a deputy collector with the east India company to look after his wife's estate. He furnished the Observatory (in 1874) with a 6 inch Cooke equatorial, a transit circle, and a sidereal clock. He communicated his observations of solar eclipses, transits of Venus and Mercury, and comets to British astronomers and the Royal Astronomical Society. He obtained equipment for celestial photography but

TIME AND SPACE

THE NEW SCIENTIFIC THEORY

(For "The Statesman.")

Dr. N. N. Saha, Lecturer on Physics at the Calcutta University, writes as follows:—

The announcement conveyed in yesterday's Reuter's cable that Professor Einstein's theory of the equivalence of Time and Space has at last been verified by observations made during the last total solar eclipse will be hailed with joy by scientific circles all over the world. If the anouncement be true, then the time-honoured dogma, that time and space are quite independent of each other, will be subverted once for all.

It is not possible to convey, without the use of proper mathematical symbols, a very precise concept of the greatness of the discovery. The theory of relativity was first formulated by the great Dutch physicist, H. A. Lorentz, during the closing years of the last century, but was largely recast and elaborated by Einstein, then a rising mathematical physicist of Switzerland, and Minkowski, a Russian Jew, whom

11. A clipping from The *Statesman*, Calcutta, 13 November 1919, showing Meghnad Saha's report on experimental verification of Einstein's theory of general relativity. Note that Saha's first initial is misprinted.

died before he could instal it. He was also the honorary meteorological reporter to the government of India for Vizagapatam. His son Raja A.V. Jugga Rao Bahadur (d.1921) served as the Vice-President of Astronomical Society of India for a year 1911-12. The Observatory seems to have closed down afterwards. (The site is now occupied by Dolphin hotel).

In passing, we may notice a small telescope with an unusual history. In 1938, the infamous Adolf Hitler presented a 5 inch aperture Zeiss telescope to the Rana of Nepal. In 1961, his son, the new Rana, passed on the telescope to the Everest hero Tenzing Norgay, who in turn donated it to the Himalayan Mountaineering Institute, Darjeeling, which he headed.

Although the Indian response to observational astronomy was rather lacklustre, it was pathbreaking in the field of theoretical astrophysics. While the well-placed Calcuttan astronomy enthusiasts were forming their Society, unknown to them a bright lad in the backwaters of east Bengal was making his acquaintance with astronomy. Meghnad Saha (1893-1955) wrote an essay on comet Halley in Bengali for the Dacca College magazine. As lecturers in physics in the Calcutta University Saha and Satyendranath Bose (1894 - 1974) brought out in 1920 an English translation of Einstein's papers on relativity. Reviewing it, the science magazine *Nature* wrote on 26 August 1922: 'Provided it is studied with care, the translation will nevertheless be of service to those who are unfa-

miliar with German, and wish to grapple with the pioneer works on these subjects, some of which are rather inaccessible'. 'Stimulated' by Agnes Clarke's popular books on astrophysics, Saha published in 1920 his epoch-making work on the theory of high-temperature ionization and its application to stellar atmospheres. Saha's demonstration that the spectra of far-off celestial objects can be simply understood in terms of laws of nature as we know them on earth transformed the whole universe into a terrestrial laboratory and laid the foundation of modern astrophysics. In 1923, Saha moved to Allahabad University as professor of physics where he set up a school of astrophysics, training outstanding students like Daulat Singh Kothari (1906-93). Saha was the first one to point out (in 1937) the need to make astronomical observations from outside the earth's atmosphere. He returned to Calcutta in 1938 as Palit professor. Saha and Bose, like Raman, were the foundation fellows of INSA. Saha became its President during 1937-38, Bose during 1949-50, whereas Kothari held the post during 1973-74.

At Madras, Subrahmanyan Chandrasekhar (b. 1910) for the first time applied the theory of special relativity to the problems of stellar structure and obtained preliminary results on what after his rigorous work at University of Cambridge came to be known as the Chandrasekhar mass limit. Chandrasekhar belated by received the physics Nobel prize in 1983.

Curiously, unlike the Indian physicists, pioneering relativists were trained abroad. Nikhil Ranjan Sen (1894-1963), a class fellow of Saha and Bose, joined as a lecturer in applied mathematics at Calcutta in 1917. He obtained his D.Sc. in 1921, but went to Berlin where he obtained his Ph.D. under the supervision of Prof. Von Laue. Sen's was the first Indian doctorate in relativity and he joined INSA as a foundation fellow. Vishnu Vasudeva Narlikar (1908-91) obtained his B.Sc. in 1928 from the Royal Institute of Science, Bombay, and left for Cambridge University for higher studies, thanks to financial assistance from Bombay University, Kolhapur state, and the J.N.Tata endowment. He passed the Mathematics Tripos with distinction in 1930 and went on to win the Rayleigh prize for his astronomical researches. Spurning an offer to go to California Institute of Technology, U.S.A., he accepted an invitation from Pandit Madan Mohan Malaviya, the Vice-Chancellor of Banaras Hindu University, and came to Banaras as the head of the mathematics department in 1932, where he remained for the next 28 years. He trained and guided a large number of students including Prahlad Chunilal Vaidya (b.1918), the author of the well-known Vaidya metric (1943) for the gravitational field of a radiating star. In 1955 came Amal Kumar Raychaudhuri's (b.1923) equation that has played a crucial role in investigation on singularity in relativistic cosmology.

In 1938, B.Datt from Sen's group gave the solution for a gravitationally collapsing spherical ball of dust. This solution was published in 1938 in *Zeitschrift fuer Physik*, volume

108, page 314. It precedes the more commonly known solution of Oppenheimer and Snyder. In 1947, S.Datta Majumdar (University of Calcutta) published a class of exact solutions of Einstein's equations for the case of an electrostatic field with or without spherical symmetry; these are now known as the Datta Majumdar-Papapetrou solutions.

By the time the second world war came to an end it was clear that the British rule in India would soon be over. Plans were therefore afoot to set the scientific agenda for the future. It is not very well known that during 1943-45 Indian government made sincere efforts to bring Subramanyan Chandrasekhar from Chicago to Kodaikanal. He was offered a salary three times the usual. Chandrasekhar however was 'unwilling to be placed in charge of the routine work of any observatory' and 'would prefer to have a job in University'. Although Meghnad Saha felt that 'Dr. Chandrasekhar ought to return to India to train our own boys', this was not to be. Daulat Singh Kothari was then sounded, but he 'expressed preference to continue as the Head of Department of Physics in Delhi University'.

Twenty years previously, the British Director General of Observatories had offered to Saha the number two position under Evershed at Kodaikanal. Now, in December 1945, Saha led a five-member Committee including the Indian Director-General of Observatories to Kodaikanal to prepare a plan for 'Astronomical and astrophysical observatories in India'. The Saha Committee proposed updating of astronomical facilities including, as a part of a long-range plan, 'the establishment in Northern India of an astronomical observatory provided with a large sized telescope for special stellar work'. The Saha report came in handy 20 years later when Bappu successfully pleaded for a stellar spectroscopic observatory at Kavalur in Jawadi Hills, Tamil Nadu. (The Observatory has since been named after Bappu.) As a follow-up of Saha's report, and on his own initiative, in 1955 a National Almanac Unit (renamed Positional Astronomy Centre in 1979) was set up at Calcutta with a view to helping the traditional almanac makers update their astronomical elements.

The year 1945 also saw the establishment of Tata Institute of Fundamental Research at Bombay. Its founder was Homi Jahangir Bhabha (1909-66), a brilliant physicist who shared Jawaharlal Nehru's vision of a scientific India as well as his aristocratic background. Additionally, he was related to the wealthy and enlightened industrial family of the Tatas. (Sir Dorab Tata was married to Bhabha's paternal aunt Meharbai in 1898). An important item on Tata Institute's agenda was 'experimental research on cosmic rays', in which Bhabha was personally interested. The scientific ballooning in course of time led to the advent of space astronomies in India. It was also with Bhabha's support that radio astronomy was successfully introduced in the 1960s by Govind Swarup (b. 1929).

12. Government of India's Committee for the planning of the post-war development of Astronomy and Astrophysics in India, at Kodaikanal with the Observatory staff during 21-23 December 1945. Seated from left to right are Prof. D.S. Kothari, Delhi University; Dr. S.K. Banerji, Director General of Observatories; Prof. M.N. Saha (chairman); Dr. A.L. Narayan, Director Kodaikanal Observatory; and Prof. M. Ishaque, Aligarh Muslim University, Absentee members were Prof. K.S. Krishnan, Rao Sahib T.P. Bhaskara Shastri, Prof. S. Bhagvantam, and Prof. A.C. Banerji. The Committee invited and received views from C.V. Raman and others.

Critique

We can single out three cosmic events from the past two centuries and use them as benchmarks in discussing the advent and growth of modern astronomy in India. The 1769 transit of Venus took place at a time when England and France were engaged in bitter rivalry over India. This brought positional astronomy to India as a navigational and geographical aid. The 1874 transit of Venus saw India firmly in the British grip. The new science of physical astronomy was taking shape, and the British scientific activity was commensurate with its economic and political status. Solar physics came to India because the British astronomers wanted data from sunny India, and because the government was given to understand that a study of the sun would help predict the failure of monsoons. Interestingly, the work plan prepared by the Royal Society for Kodaikanal Observatory in 1901 makes no mention of the solar-terrestrial connection. By the time comet Halley appeared in 1910, India's new middle class had become politically assertive and scientifically ambitious. While the Indians on their own remained mere dabblers in observational astronomy, they made original contribution in the fields of theoretical astrophysics and relativity, in which they no doubt felt more at home.

At the time of independence in 1947, India could boast of only two, rather outdated, observatories: central government's Solar Physics Observatory at Kodaikanal which stood where Evershed had brought it in 1911, and Osmania University's non-teaching Nizamiah Observaotry with equipment of still earlier vintage. Saha Committee's rather pious recommendation for upgradation of the astronomical facilities was on record, but there was nobody at hand to drive home the advantage. Bhabha's nascent Institute was still housed in his aunt's mansion, but was poised for take off in a big way. And finally there were a number of universities which would multiply but fail to keep the early promise.

2

Astronomical facilities

Tradition in optical astronomy, described in the previous chapter, continues. In addition, facilities have been created in radio astronomy, space astronomy, etc, and a new inter-university centre has been set up. In a rapidly advancing field that is astronomy new facilities are also being planned. This chapter provides a survey of the existing and planned astronomical facilities in the country.

Optical astronomy

During the last 40 years, the old observatories at Kodaikanal and Hyderabad have been modernized to an extent. At the same time new observatories and research institutes have appeared on the astronomical map. Kavalur, Naini Tal, Japal-Rangapur, Gurushikhar, and Udaipur cover night-time and day-time astronomy.

Vainu Bappu Observatory, Kavalur
(Indian Institute of Astrophysics)

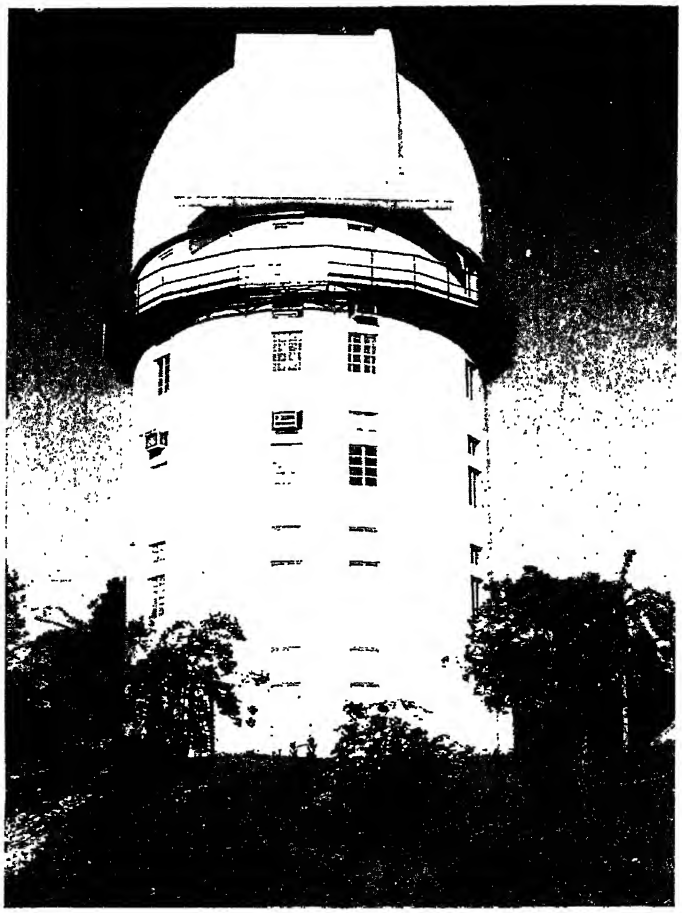
Kavalur Observatory (long. 78°49′ 54″ E, lat. 12°34′ 32.2″ N, alt. 725m) located amidst sandalwood forests in Jawadi Hills in the North Arcot district of Tamil Nadu, was set up in 1968 as a part of the Kodaikanal Observatory. On 1 April 1971, the Kodaikanal Observatory was made into the Indian Institute of Astrophysics. (Its headquarters are at Bangalore.) On 6 January 1986, the Kavalur Observatory, as well as its 2.3m telescope, was named after the founder, M.K. Vainu Bappu.

FACILITIES

There are four major telescopes at Kavalur: (i) 2.3m aperture Vainu Bappu Telescope (VBT), (ii) 1m Carl Zeiss telescope, the Observatory's workhorse since 1972, (iii) a 75cm telescope, and (iv) a 45cm Schmidt telescope. There are in addition a number of smaller telescopes, including a 34cm telescope installed on an old mounting.

The VBT has two foci: an f/3.25 prime focus, and an f/13 Cassegrain focus. The original plan for an f/30 coudé focus has been abandoned; it is now proposed to link it through an optical fibre to the prime focus. The prime focus (scale: 27 arcsec mm^{-1}) is used with a Wynne corrector system which provides a wide field of 20 arcmin diameter. This arrangement is used essentially in imaging mode in various filters with a liquid nitrogen-cooled CCD camera system. The present set up is based on the astronomical system containing a GEC chip of 385 x 576 pixels and operated through a PC based data acquisition system. All operations of object acquisition and monitoring as well as data acquisition are remote controlled.

At the Cassegrain focus the main instrument in operation is a Boller and Chivens spectrograph with a 15cm camera and the Astromed CCD system as the detector unit. The



13. The dome housing the 1m telescope at Kavalur. An identical telescope is at Naini Tal.

combination of various gratings currently available give resolutions (two pixels) ranging from 2.7Å to 10.8Å. Recently this spectrograph placed on the observing floor (i.e. decoupled from the telescope) has been linked with the prime focus by a 20m long optical fibre. The other instruments which are extensively used at Cassegrain focus are an automated polarimeter (developed by Physical Research Laboratory) and a two-star photometer (built by Indian Space Research Organization) which is optimized especially for high-speed photometric observations in various filters. Several other instruments are also used with VBT by visiting observers: e.g., an infrared photometer and a Fabry-Perot spectrometer.

The 1m Carl Zeiss telescope is of Ritchey-Chretien type normally operated at Cassegrain focus with an f/13 beam (scale: 16 arcsec mm^{-1}). There is provision to have f/6 and f/2 beams also. In addition an f/30 coudé focus is also available. The major auxiliary instruments currently available at the 1m telescope are the following.

A direct imaging camera with plate holders of different sizes and with a provision to place filters is available (though not in regular use). Currently the imaging mode is operated with a Photometrics CCD system which contains a 576 x 384 pixel Thomson chip and a dedicated computer system for data acquisition. Imaging in various narrow and wide bands is done regularly. Low and medium resolution spectroscopy is done with a Zeiss Universal Astronomical Grating Spectrograph adapted with a 25cm camera. The CCD system described above gives a resolution ranging from 11.4Å to 2.5Å. The other regular instruments in use at Cassegrain focus are a UBVRI polarimeter for linear polarization studies; a single-channel UBVRI photoelectric photometer; and a PC-controlled single-channel spectrum scanner for broadband work. The data in these systems are acquired in digital mode through a PC. The f/30 coudé focus feeds two high resolution spectrographs. The most extensively used is the echelle spectrograph (using a 76 lines mm^{-1} R2 echelle with a 150 lines mm^{-1} cross dispersion grating) coupled with a 25cm camera. It gives a resolution of 0.4Å. The detector system is the Photometrics CCD system. The other higher dispersion spectrograph has a 400 lines mm^{-1} grating and a 120-inch camera yielding a dispersion of 2.8Å mm^{-1} in the blue.

The 75cm telescope is also operated at the f/13 Cassegrain focus. A UBVRI photometer coupled to a PC-based data acquisition system is the regular instrument in use. An InSb infrared JHKL photometer is also being modified for use at this telescope. The 45cm Schmidt telescope started functioning in 1985. The plate scale is about 150 arcsec mm^{-1}. A field of 3° x 4° can be obtained. The 34cm reflector is provided with a 1P21 photomultiplier and is used extensively for BV photometry of variable stars.

At VBO the other facilities include a VAX 11/780 (VMS) computer system where `Starlink' and `Respect' software packages are in regular use for data reduction and image processing. Soon there would be a workstation to enhance the data reduction capability. The infrastructural support includes a mechanical workshop and an electronics laboratory to service, maintain and in some cases fabricate the auxiliary instruments and telescopes. There are also two aluminizing chambers to regularly aluminize the telescope mirrors up to a size of 2.5m.

FUTURE PLANS

Very shortly VBO would be commissioning a new CCD camera with a 1024 x 1024 pixel chip which can provide a wider field for imaging. An elaborate object acquisition and guiding unit is under fabrication for the Cassegrain focus of VBT. One of the important instruments being planned is a fibre-linked coudé echelle spectrograph which will provide a spectral resolution of about 50,000.

Nizamiah and Japal-Rangapur Observatories and Department of Astronomy

(Osmania University, Hyderabad)

Nizamiah Observatory was nominally set up in 1901 as a private observatory. It was taken over by the Hyderabad government in 1908, and attached to the Osmania University in 1919. Plans for the modernization of the Observatory were initiated by the University Grants Commission in 1954, with most of the funds coming from the U.S. Government through the India Wheat Loan Educational Exchange Programme. The Department of Astronomy was set up in 1959, and received special grant during 1964-79. An order was placed in 1957 with Messers J.W.Fecker of Pittsburgh for the supply of a 48 inch (1.2m) reflector. The telescope parts were received in December 1964, and the telescope was finally commissioned in December 1968 at the new site (long. 76° 13′ 39″ E, lat. 17° 05′ 54″ N, alt. 695m) named Japal-Rangapur after the two neighbouring villages. In 1983 the historic Begumpet site was vacated and Nizamiah Observatory shifted to a new building in the Osmania University campus.

FACILITIES

The 1.2m Fecker reflector is provided, at its f/3.5 prime focus, with a Baker corrector system giving a wide field of 3° x 3°. The following instruments are available at the f/13.7 Nasmyth focus:

- a dual channel photoelectric photometer with direct current and photon counting systems
- a Meinel spectrograph with plane gratings giving dispersions of 132, 66, and 33Å mm^{-1} in blue
- a scanning spectrometer with micro-processor based system control and data logging, with provision for recording the signal in 2000 channels in direct mode
- a 512 x 512 element CCD imaging system

The f/13, 38cm, Grubb refractor (at the Osmania University campus) is provided with

- a photoelectric photometer equipped with a GR amplifier and a Honeywell strip chart recorder
- a filar micrometer for measurement of visual binaries.

The 20cm, f/15, astrograph has a photographic plate holder for 16cm x 16cm plates. It also has an attached 10 inch refractor guiding telescope with provision for X, Y motion of the eyepiece for off-set guiding.

The solar radio telescope system consists of the following :

- a 3m parabolic dish antenna with dual polarized horn feed
- an x-band signal generator
- a radiometer receiver
- a time-sharing polarimeter
- a two-channel and a four-channel recorder
- a 16 element Yagi T-array for metre-wavelength solar studies.

In addition the Observatories have two Gaertner spectroscopic and one photographic plate-measuring machines, and a Carl Zeiss micro-densitometer with analogue recording. The computer facility consists of a DCM Spectrum-3 microcomputer with 64K byte memory and a number of personal computers.

FUTURE PLANS

The mechanical and electrical drive system of the 1.2m telescope will be modernized to make the telescope more effective. A high - dispersion Echelle spectrograph with blue and red image tubes is under construction. The image tubes will later be replaced by CCDs. A 1024 x 1024 element CCD and a Sun work station are being acquired.

Uttar Pradesh State Observatory, Naini Tal

The first observatory to be set up in India after independence, it was started in April 1954 at the old city of Varanasi by the Uttar Pradesh government on the initiative of a cabinet minister and future chief minister, Dr Sampurnanand, himself a Sanskrit scholar with interest in all aspects of astronomy. The Observatory was placed under the honorary directorship of Avadesh Narayan Singh, at the time principal of Dev Singh Bisht Government Degree College, Naini Tal. In November 1955, the Observatory, with M.K. Vainu Bappu as the Chief Astronomer (as the Director was then called), was moved to Naini Tal town. In 1961, the Observatory shifted to its present site on Manora Peak (long. 79° 27′ 24″ E, lat. 29° 21′ 36″ N, alt. 1950m), in Naini Tal.

FACILITIES

To begin with, the Observatory was rather modestly equipped; it had a gravity-driven 25cm refractor by Cooke and a 13cm transit instrument. Over the years, it acquired progressively bigger telescopes: a 38cm reflector by J.W.Fecker (1959); a 56cm reflector by Cox Hargreaves & Thomson (1968); and finally a 1m Zeiss reflector (1972) that has since been formally named the Sampurnanand Telescope. There is, in addition, a 50/79mm, f/1, Schmidt camera on a triaxial mount, which was used for satellite tracking during 1958-79.

A number of instruments are available for use at the f/13 Cassegrain focus of the 1m reflector :

- a plate-holder with a field of 45 arcmin^2
- a spectrograph having dispersion in the range 30-150 Å mm^{-1}
- an f/2 Meinel camera with a field diameter of 37.5 aremin
- a photoelectric photometer
- a CCD camera with a Thomson chip of 576 x 384 elements of 23 micron size
- a grating spectrometer with a reticon array of 1024 elements of 25 micron width, providing dispersion of 0.25nm and 0.215nm per element.

An infrared photometer for near-infrared studies is under test. Also, a 1024 x 1024 Tektronics CCD chip with a pixel size of 24 micron has been acquired. The 56cm reflector is provided with two objective prisms and a Baker corrector for photography at the Newtonian focus. There is also a photometer at the folded Cassegrain focus. The 38cm reflector is used in conjunction with a photometer.

The facilities available for solar research are as follows. (i) A 9m focus, Czerney-Turner type horizontal spectrograph with a dispersive power of 1.2Å mm^{-1} in the first order is fed by a 45cm diameter coelostat through a 25cm, f/66, off-axis skew Cassegrain telescope. (ii) Another system consisting of a 25cm coelostat and a 15cm, f/15, objective lens produces a 16/24mm solar image through a Halle H-alpha filter. (iii) Two recently acquired 15cm, f/15, coudé refractors are being used for obtaining filtergrams in H-alpha, Ca II K, and CN filters and for white light solar photographs.

The computer facilities consist of a Micro Vax II, a Sun-Sparc computer, a Vax station, and a number of personal computers. Reduction packages MIDAS, VISTA, and IRAF are available. The Observatory has an in-house optical workshop, machine shop, aluminizing laboratory, and electronics workshop.

FUTURE PLANS

Subject to availability of funds, there is a proposal to set up a 50cm vacuum solar optical telescope with a view to carrying out high spatial and temporal resolution studies of solar flares and associated active regions. It is planned to obtain filtergram and corresponding magnetogram data so that solar activity can be understood in an integrated manner.

Gurushikhar Infrared Observatory
(Physical Research Laboratory)

The Gurushikhar Observatory, Mount Abu, in south Rajasthan (long. 72° 46′ 47.5″ E, lat. 24° 39′ 8.8″ N, alt. 1680m) is a part of the Physical Research Laboratory, Ahmedabad. Clear nights at the site average 200-250 a year, with the observing season extending from October to May. During the dry winter months, precipitable water vapour over Gurushikhar has a typical value of about 3mm. The Observatory houses a 1.2m reflector with an f/13 Cassegrain focus. A high-resolution Fourier transform spectrometer, an infrared polarimeter, and near-infrared array detector camera are being installed. It is planned to install, in about a year's time, an f/45 vibrating secondary and coudé focus.

The astronomy group at PRL has developed expertise in focal plane instruments for special studies. These include high-resolution Fabry-Perot spectrometers, both aperture scanned and two dimensional imaging versions; a stellar photometer and infrared photometers with 1 ms time resolution.

Kodaikanal Observatory
(Indian Institute of Astrophysics)

Established as a solar physics observatory in 1899, Kodaikanal Observatory (long. 77° 28′ 07″ E, lat. 10° 13′ 50″ N, alt. 2343m) is now a field station of the Indian Institute of Astrophysics.

FACILITIES

(i) A 15cm aperture English-mounted refractor by Lerebours and Secretan of Paris, acquired in 1850, but remodelled by Sir Howard Grubb in 1898 to serve as a photoheliograph, giving 20cm diameter white-light pictures of the sun.

(ii) Twin spectroheliographs, giving 6cm diameter full-disc photographs of the sun in Ca K and H-alpha light. The arrangement consists of a 46cm diameter Foucault siderostat which feeds light to a 30cm aperture, f/22, Cooke triplet lens. The two-prism Ca II K spectroheliograph was acquired in 1904 from Cambridge Scientific Instruments Co., while the grating H-alpha spectroheliograph was bolted onto the original instrument by Evershed in 1911.

(iii) A Hale spectrohelioscope for visual observations of the sun, received as a gift from Mount Wilson Observatory in 1933.

14. The dome of the solar tunnel telescope at Kodaikanal. To the left can be seen the spectroheliograph building with the Bhavnagar dome in the background. To the right is a radio antenna no longer in use.

(iv) The tunnel telescope by Grubb Parsons, purchased in 1958, consists of a 60cm diameter two-mirror coelostat (mounted on a 11m high tower) that directs light via a flat mirror to a 38cm aperture, f/90, achromat which forms a 34cm diameter solar image at the focal plane. A littrow-type spectrograph and a spectroheliograph capable of giving pictures in a chosen line are available for use. These remain the country's main facilities for high spatial (5.5 arcsec mm^{-1}) and spectral resolution (up to 9Å mm^{-1}) solar work.

(v) A PC-based spectropolarimeter for measuring all three components of the solar magnetic field was built in 1992. This has an asynchronous Peltier-cooled CCD camera for recording the Zeeman-broadened spectra, a microprocessor-based, stepper motor that rotates the modulating retarder plate, and a video frame grabber that can digitize and store 16 frames of 512 x 512 pixels at a rate of 170ms per frame.

FUTURE PLANS

It is planned to modernize solar observational facilities. Arrangements are being made to obtain filtergrams in Hα and Ca II K, using narrow-band filters and large-format charge coupled devices. A Zeiss double monochromator is being installed to obtain scatter-free spectra. In the case of the tunnel telescope, it is planned to improve image stability and guiding, and instal CCD detectors. Replacement of the old lens and grating would reduce scattered light in the spectrograph. The spectroheliograph is being provided with a linear reticon detector for improving spectral resolution. It will also enable acquisition of spectroheliograms in narrow absorption lines.

Udaipur Solar Observatory

(Physical Research Laboratory)

The Udaipur Solar Observatory (long. 73°42′ 45″ E, lat. 24°35′ 08″ N, alt. 301m) was set up in 1975 on a small island in the Fatehsagar lake in Udaipur, under the aegis of the Vedhshala Trust, Ahmedabad. In December 1981, the Observatory was taken over by the government of India's department of space, and attached to the Physical Research Laboratory, Ahmedabad.

FACILITIES

The Observatory began its scientific work with an old 10 foot spar telescope, received as a gift from CSIRO, Australia. The telescope has been considerably modified. A 25cm aperture singlet objective lens has been installed on the spar, for taking H-alpha chromospheric pictures with 35mm film and video camera. In addition, a 15cm aperture telescope has also been mounted on the spar for taking white light pictures of the solar disc. A Razdow telescope has been acquired

from the National Oceanic and Atmospheric Administration, U.S.A. for monitoring full-disc chromospheric activity. A coudé 15cm aperture telescope by Zeiss with a Littrow spectrograph is available for taking multislit spectrograms of flares, prominences, etc. in H-alpha light. A digital data acquisition system has been acquired. All solar telescopes are equipped with solar guiders. It is now planned to instal a piezo-electric driven image stabilizer. Efforts are under way to build a photoelectric scanning spectrograph to obtain spectroheliograms in Helium 10830Å line. Efforts are also being made to build a video magnetograph for measuring longitudinal magnetic and velocity fields, using a lithium niobate solid Fabry-Perot etalon as a narrow-band (0.13Å passband) filter.

Proposed National Large Optical Telescope

There are at present in the country four 1m class telescopes and one 2m class telescope. A proposal has been put forward to the government of India for a larger telescope. The proposed 4m-class telescope would incorporate the following three features in common with the present-day large telescopes: (i) a fast and light-weight primary mirror, (ii) an altazimuth mount for compact mechanical structure, and (iii) active correction of the optics during the observations for obtaining a sharp image. A well equipped telescope of the proposed type would allow imaging of objects brighter than about 27mag arcsec^{-2} as well as medium-resolution (about 1Å) spectroscopy to a limiting magnitude of about 21 in visible band. The Himalayan ranges offer the best possibility for a suitable site.

Radio astronomy

Radio astronomy made its debut in India in 1952 when Kodaikanal Observatory built a 100MHz radio telescope with a twin Yagi antenna for monitoring solar noise. Over the years a number of receivers were built for operation at other frequencies. In 1956, the Observatory obtained a custom-built 10cm wavelength radio receiver from the Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia. (The receiver was put to use in 1965.) These early efforts at Kodaikanal however remained non-cumulative. In 1956 Physical Research Laboratory (PRL) set up a simple radio telescope to monitor galactic radio noise with a view to studying the earth's upper atmosphere. In 1964 an ionospheric opacity meter was built for measuring ionosphere attenuation at 21.3MHz. In July 1967 a solar radio spectroscope operating at 40-240MHz was installed. This instrument fills a gap between the far-eastern and European stations for a round-the-clock patrol of solar bursts. In 1969 a time-sharing radio photometer

operating at 35MHz was set up, and the next year a Dicke-switched type microwave (2800MHz) solar radiometer.

Radio astronomy came to its own in 1963 at Tata Institute of Fundamental Research, Bombay. The first radio telescope under the new auspices was a grating-type radio interferometer, set up at Kalyan near Bombay, for observing the sun at 610MHz with an angular resolution of 2.3 arcmin x 5.2 arcmin. The interferometer was assembled from '32 parabolic dishes from CSIRO of Australia lying unpacked for several years at NPL [National Physical Laboratory], New Delhi'. It was in use during 1965-68.

Radio-astronomical facilities now exist at Udhagamandalam (Ooty), Bangalore, Gauribidanur, Thaltej in Ahmedabad, and at the small village of Khodad near Pune.

National Centre for Radio Astrophysics,Pune

(Tata Institute of Fundamental Research)

FACILITIES

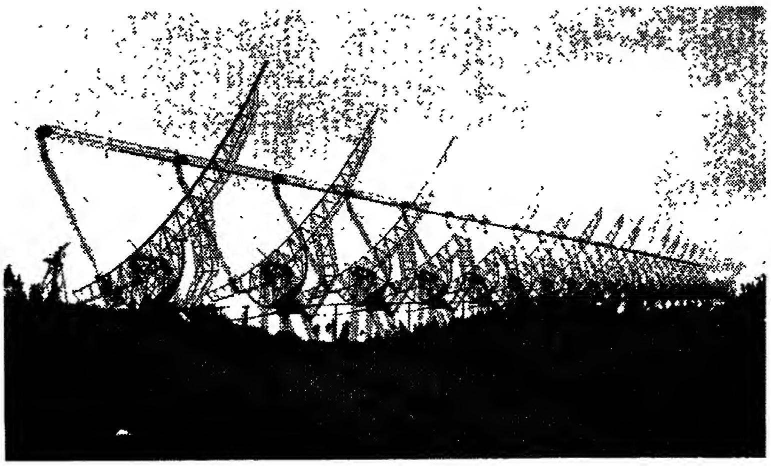
Ooty Radio Telescope

The first major radio astronomical facility, the Ooty Radio Telescope (ORT) at Udhagamandalam in Nilgiri Hills, Tamil Nadu, became operational in 1970. It consists of a parabolic cylinder 530m long and 30m wide. The reflecting surface is made of 1100 thin stainless steel wires running parallel to each other for the entire length of the cylinder. The surface is supported by 24 parabolic frames 23m apart. The telescope is installed on a hill which has a natural slope of about 11°, close to Ooty's geographical latitude. The long axis of the telescope has been aligned in the north-south direction so that the long rotation axis of the telescope is parallel to the earth's rotation axis. The arrangement makes it possible to track celestial radio sources for about 9.5 hours every day by a mechanical rotation of the parabolic frames in the east-west direction. In the north-south direction the beam can be steered by introducing appropriate phase shifts between the 1056 dipoles along the focal line of the parabolic reflector. At the operational frequency of 326.5MHz, the half-power beam width is about 2° in the east-west and about 5.6 arcmin in the north-west. The sensitivity of the Ooty telescope has recently been improved by a factor of about four by installing a new feed system. The overall system temperature is about 150K. The effective collecting area of about 8000m^2 is equivalent to a 130m diameter parabolic dish with an aperture efficiency of about 60%.

One of the principal objectives of the telescope has been the determination of the brightness distribution of a large number of weak and distant extragalactic radio sources, using lunar occultation technique. In addition, the telescope has been used for studying pulsars, supernova remnants, interplanetary and interstellar scintillations, and recombination lines. Protoclusters have been looked for and attempts have been made to detect the deuterium line. The telescope has also been used in Very Long Baseline Interferometric (VLBI) observations in conjunction with large radio telescopes in Europe including Russia. With improved sensitivity, the telescope is now being extensively used to search for new pulsars. Another major programme currently under way is the mapping of the disturbances in the solar wind by monitoring the interplanetary scintillation of a large number of radio sources round the year. There is also a plan to undertake a survey of the plane of our galaxy by observing recombination lines at 327MHz.

Ooty Synthesis Radio Telescope

An aperture synthesis telescope at Ooty was set up in the early eighties using ORT as the main element and by installing seven small low-cost parabolic cylinders of size 22m x 9m at distances of up to 4km from ORT. In order to achieve a wide field of view, ORT was itself divided into five sections and the signals received from the 12 antenna elements were mutually combined to form a total of 66 interferometer pairs. The resulting image had a resolution of about 1 arcmin at 327MHz. The synthesis array was used for studying many galactic and extragalactic radio sources. Its operation has since been discontinued in view of the much more powerful Giant Metre-wave Radio Telescope being built.



15. The 530m-long Ooty Radio Telescope.

Giant Metre-wave Radio Telescope

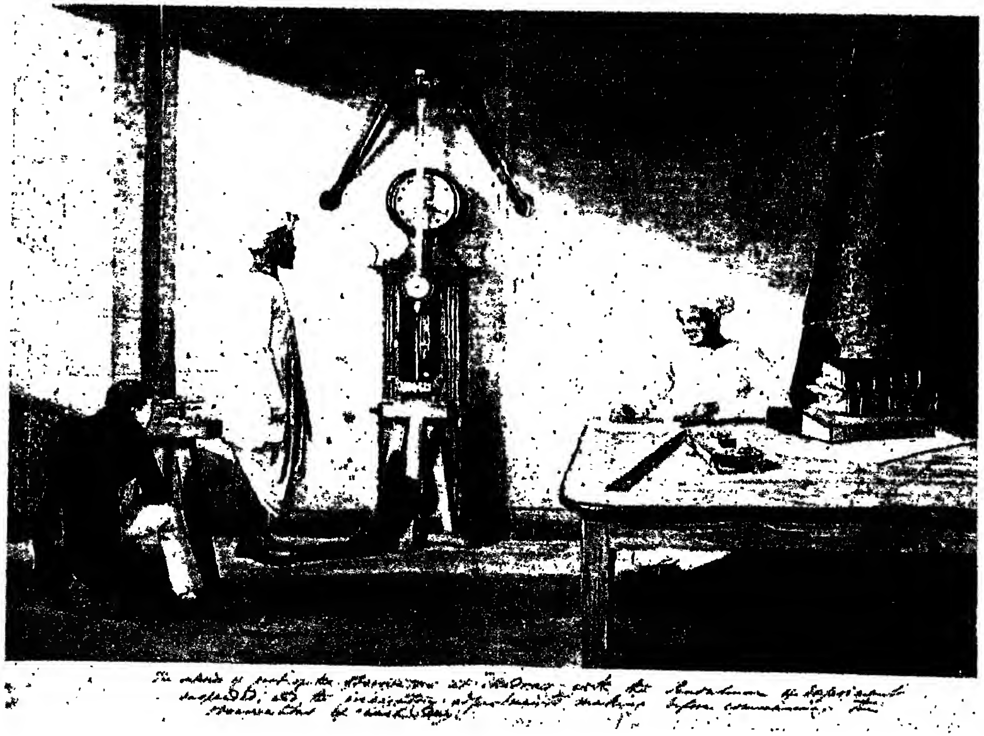
The Giant Metre-wave Radio Telescope (GMRT) now under construction near Khodad (site long. 74° 03′ E, lat. 19° 06′ N, alt. 650m), about 80km north of Pune, will be the world's largest aperture synthesis radio telescope at metre wavelengths. Expected to be fully operational by 1995 end, it consists of 30 fully steerable parabolic dishes of 45m diameter each. Fourteen of the dishes are being located in a compact central array in a 1 km x 1 km area. The remaining 16 will be placed along the three arms of an approximately Y-shaped configuration spread over a 25km^2 region. The telescope will operate in six frequency bands, around 50, 153, 233, 327, 610, and 1420MHz, with angular resolution ranging from about 60 arcsec at the lowest frequencies to about 2 arcsec at the highest. The metre-wave part of the radio spectrum has remained largely unexplored, in part due to large-scale man-made interference at these wavelengths in the west. Fortunately for astronomers, radio interference is not a serious problem in India at present. A novel, cost-cutting, feature of the design is the low-solidity concept of Stretched Mesh Attached to Rope Trusses (SMART), specially suited for non-Himalayan India where there is no snowfall. GMRT will have over three times the collecting area of the Very Large Array (VLA) in New Mexico, U.S.A., currently the most powerful aperture synthesis telescope. At 327MHz, GMRT's sensitivity will be about eight times higher than that of the VLA because of the larger collecting area, higher antenna efficiency, and a substantially wider usable bandwidth because of the low level of man-made radio noise in India.

Although the telescope would be truly versatile, an important objective is to search for the highly red-shifted line of neutral hydrogen emanating from protogalaxies or protoclusters, with a view to determining the epoch of galaxy formation. (The hydrogen line from clouds between a red shift of three and ten should be observable at frequencies between about 350 and 130MHz). In addition, GMRT will especially endeavour to search for short-period, especially millisecond, pulsars, and hopes to be able to bring about a three to four fold increase in the total number of known pulsars in the Galaxy.

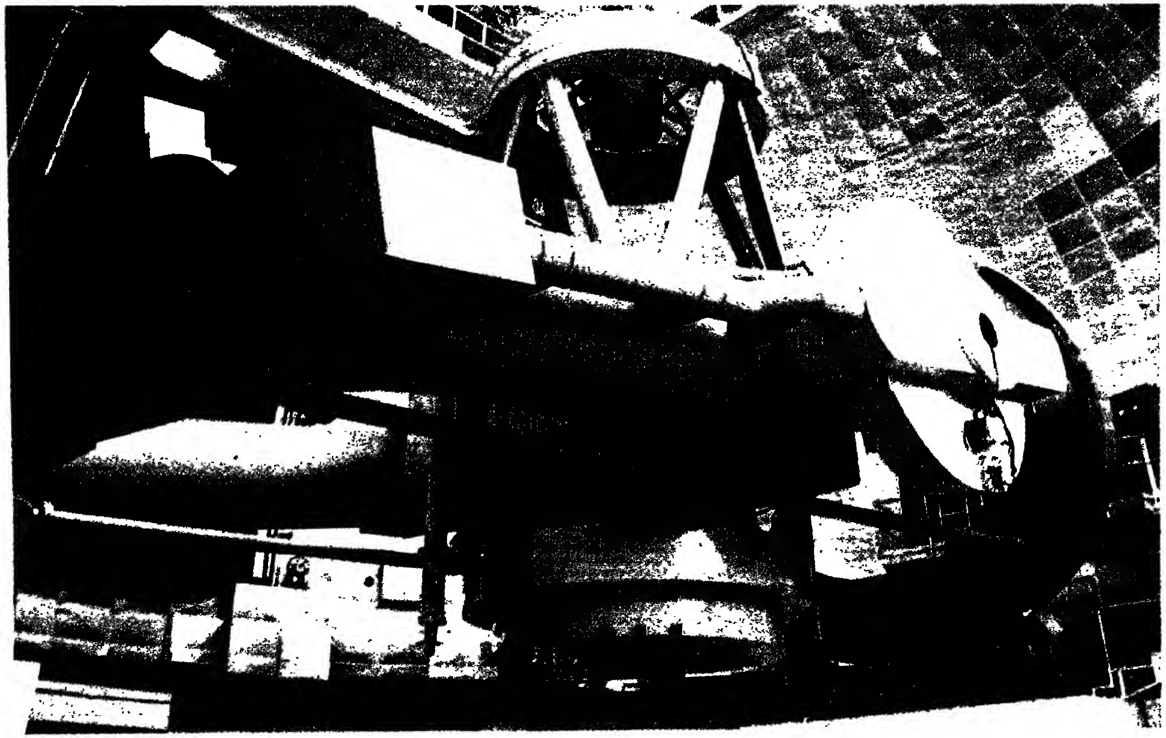
Raman Research Institute, Bangalore

The Raman Research Institute founded by C.V.Raman in the late 1940s was reorganized, after his death in 1970, as a national institute for research in basic science. It is being funded by the government of India's department of science and technology since 1972. The main areas of research are radio astronomy, theoretical astrophysics, general relativity and gravitation, and liquid crystals.

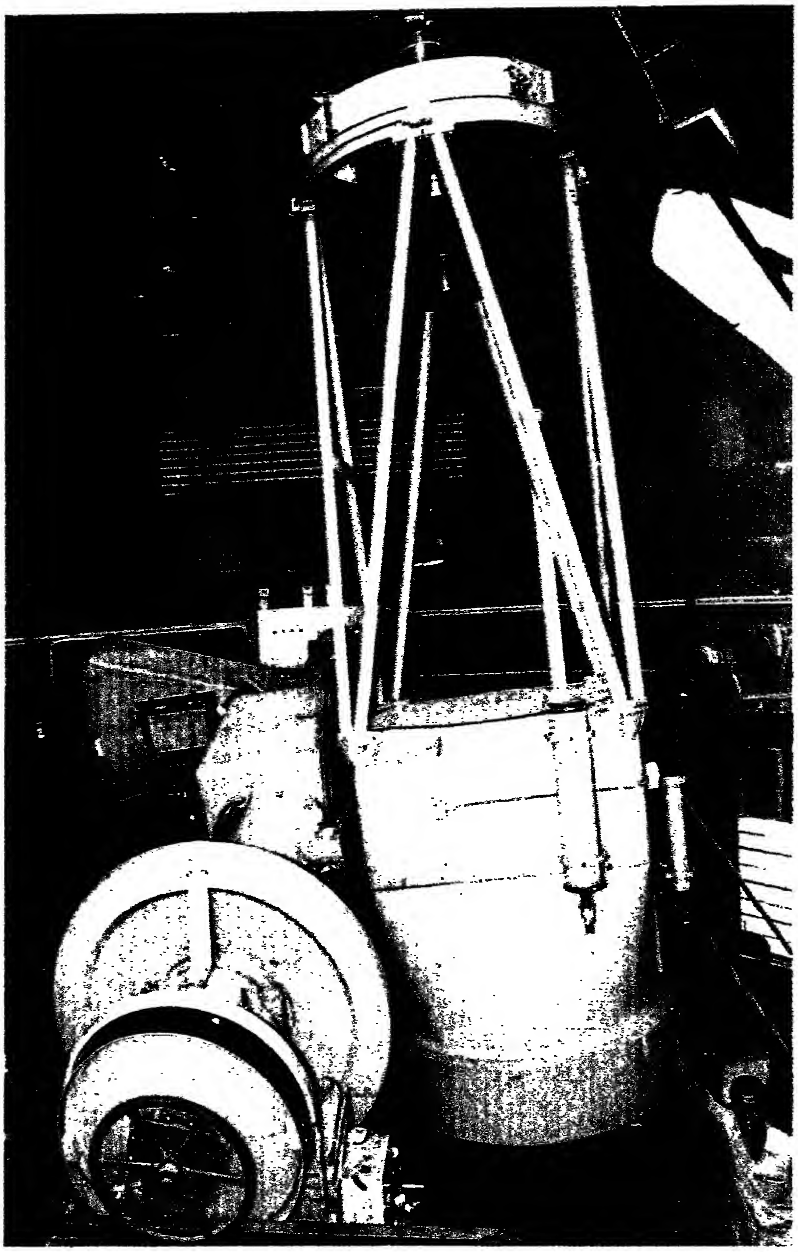
C1. Bhaskara II's daughter Lilavati (after whom the book is named) and her fiance are trying to determine a chosen moment of time by observing the slow sinking of a small vessel (*ghatika*) in a tray full of water. According to the legend, unknown to any body, a pearl from Lilavati's jewellery blocked the hole in the *ghatika* making the observers lose track of time. The book *Lilavati* was translated by Abul Fazal Faizi in AD 1587 on Akbar's orders. This Lahore style painting accompanies a copy made by Pandit Dayaram in AD 1857 (Salar Jung Museum, Hyderabad).



C2. John Goldingham swinging a Kater's pendulum in front of a Haswell clock at Madras Observatory, 1821. The assistants are Teroovencatachary (left) and Senavassachary (right). Partly visible in the right is the 18ft high granite pillar, which can still be seen at Madras (The Royal Society, London).

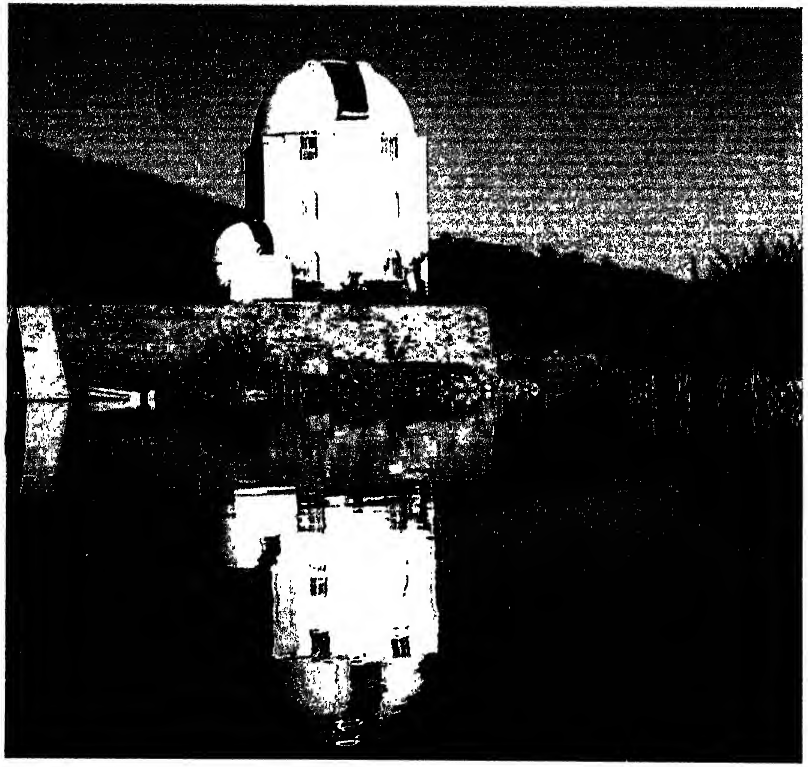
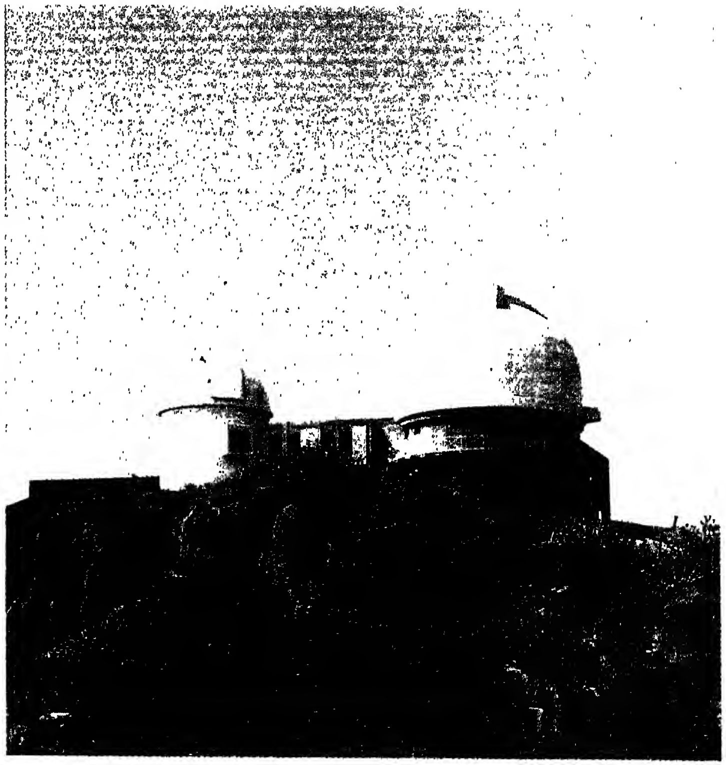


C3. The 2.3m Vainu Bappu Telescope at Vainu Bappu Observatory, Kavalur.

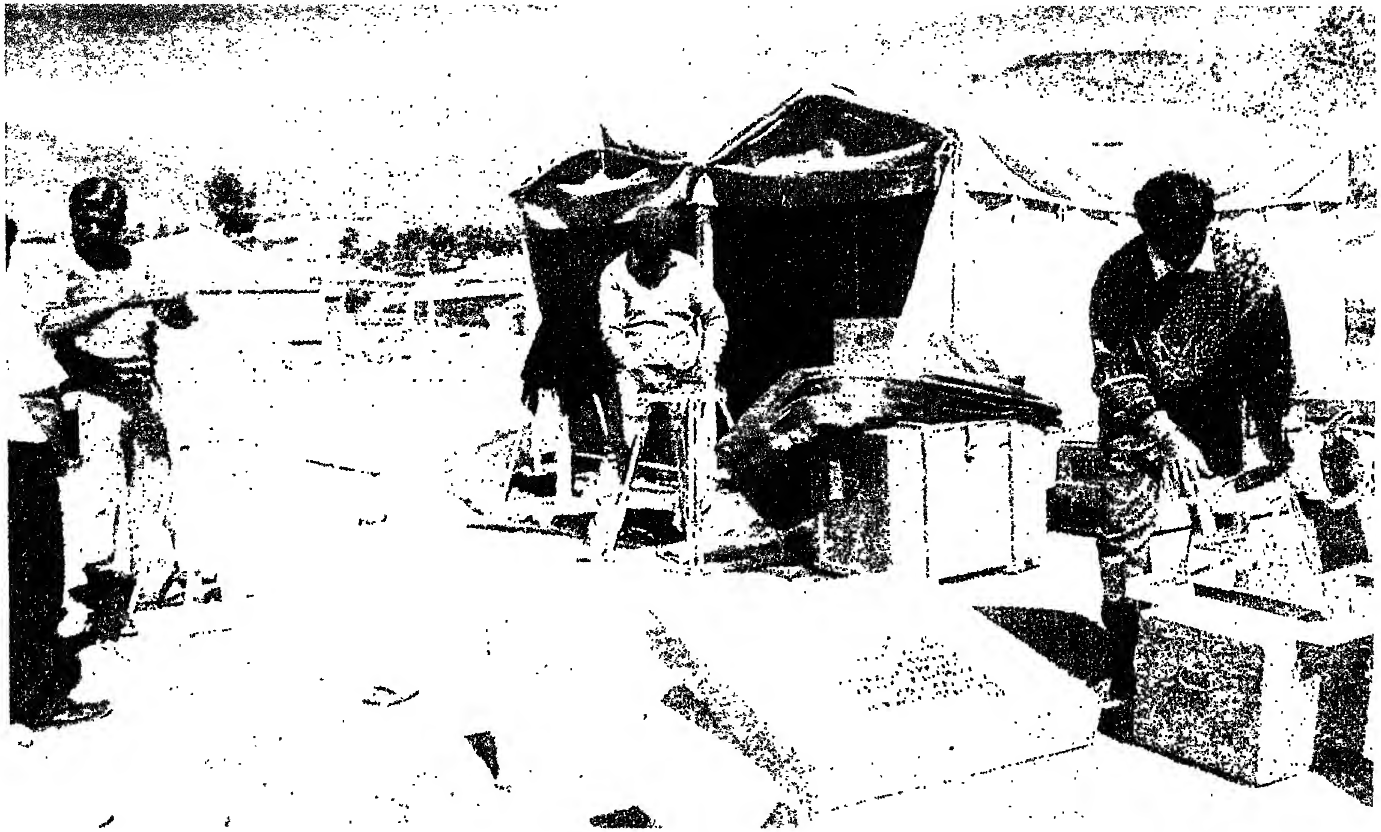


C4. The 1.2m Fecker telescope at Japal-Rangapur Observatory.

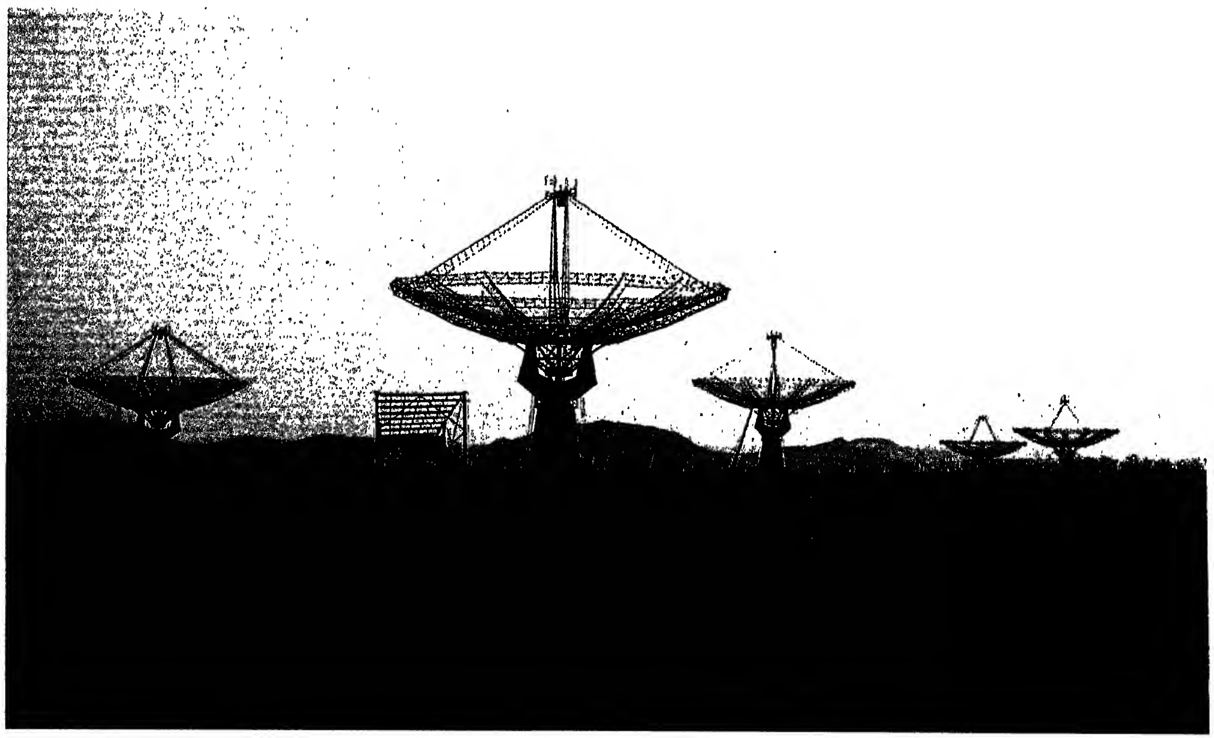
C5. CCD camera mounted at the Cassegrain focus of the 1m telescope at Uttar Pradesh State Observatory, Naini Tal.

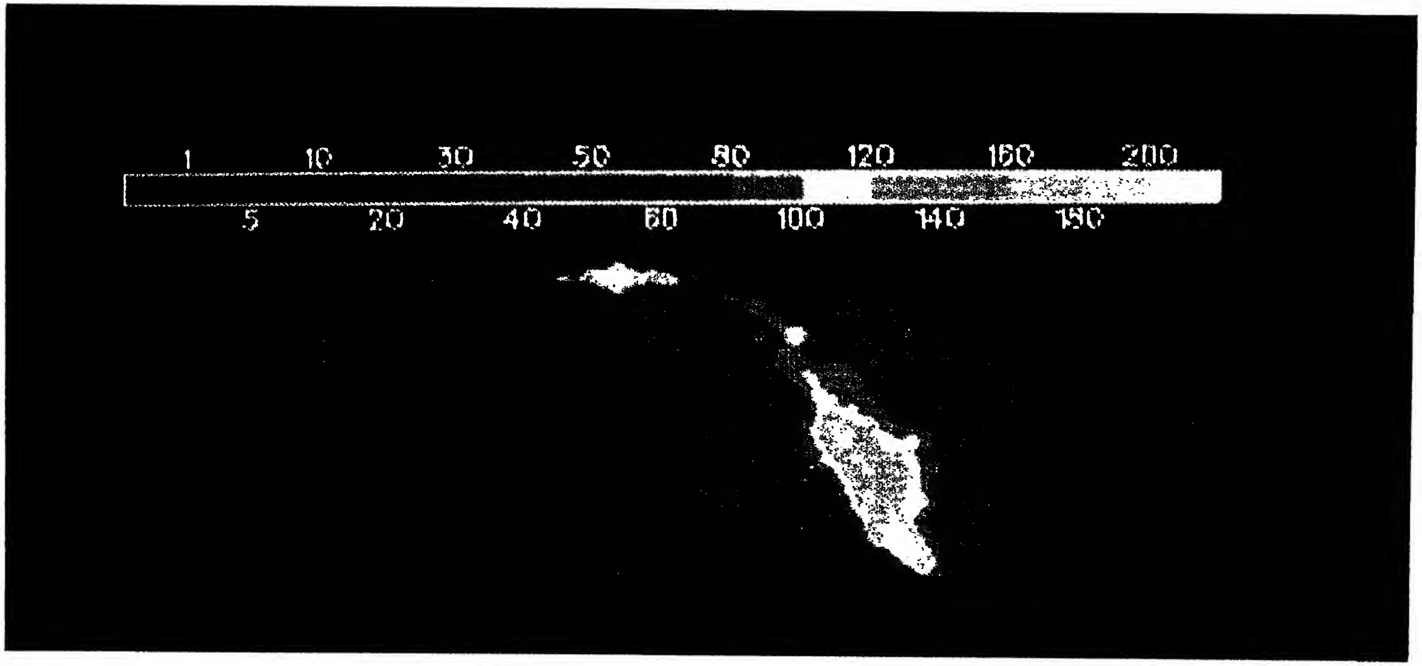
C6. Right: Gurushikhar Infrared Observatory : View of the main building and the smaller dome from the rear. Left: Udaipur Solar Observatory.



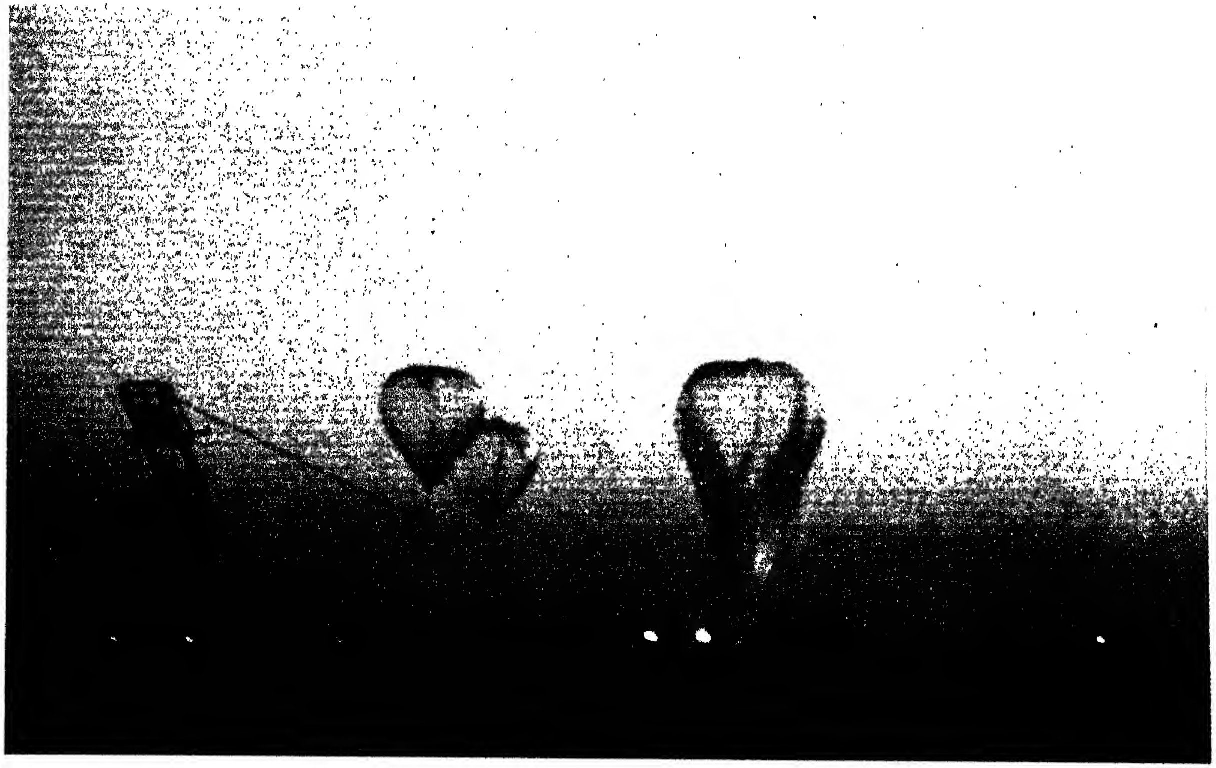
C.7 Indian astronomical camp at Putre, north Chile, for observing the total solar eclipse of 3 November 1994. (Reprinted from *Estella de Arica* of 29 October 1994.)



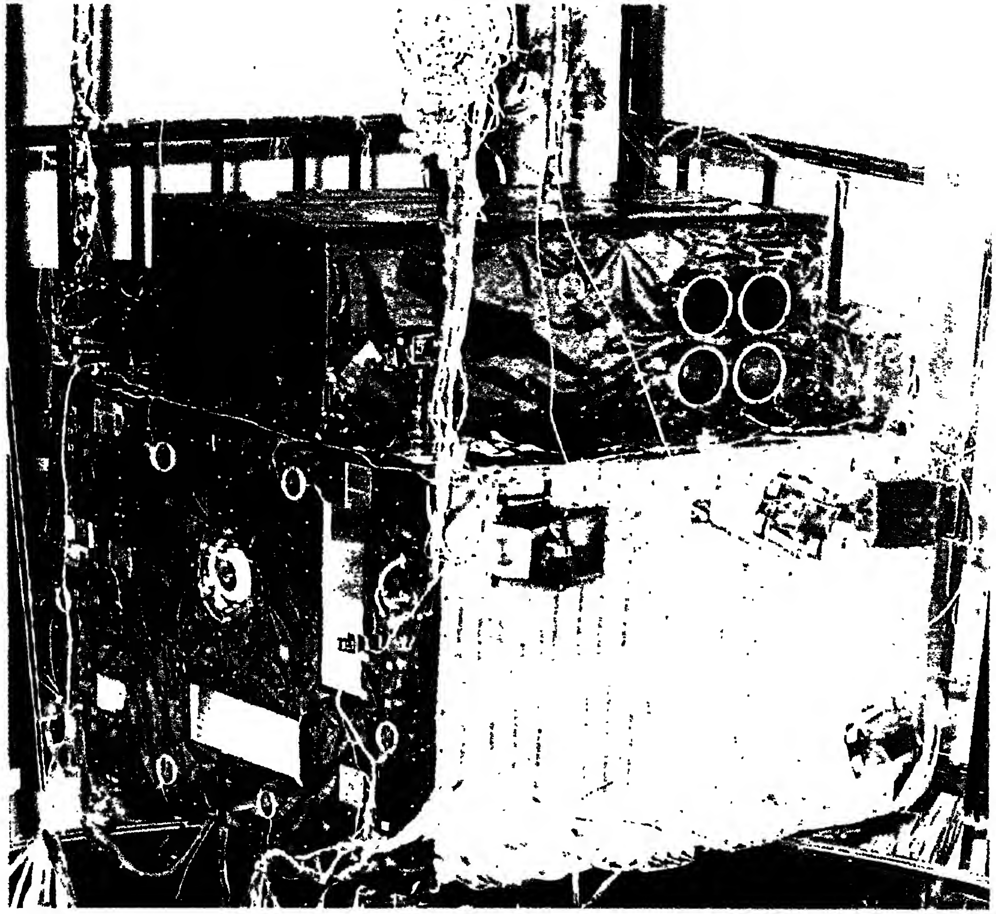
C8. The 'central square' of the Giant Metre-wave Radio Telescope at Khodad containing 14 of the 30 parabolic dishes.



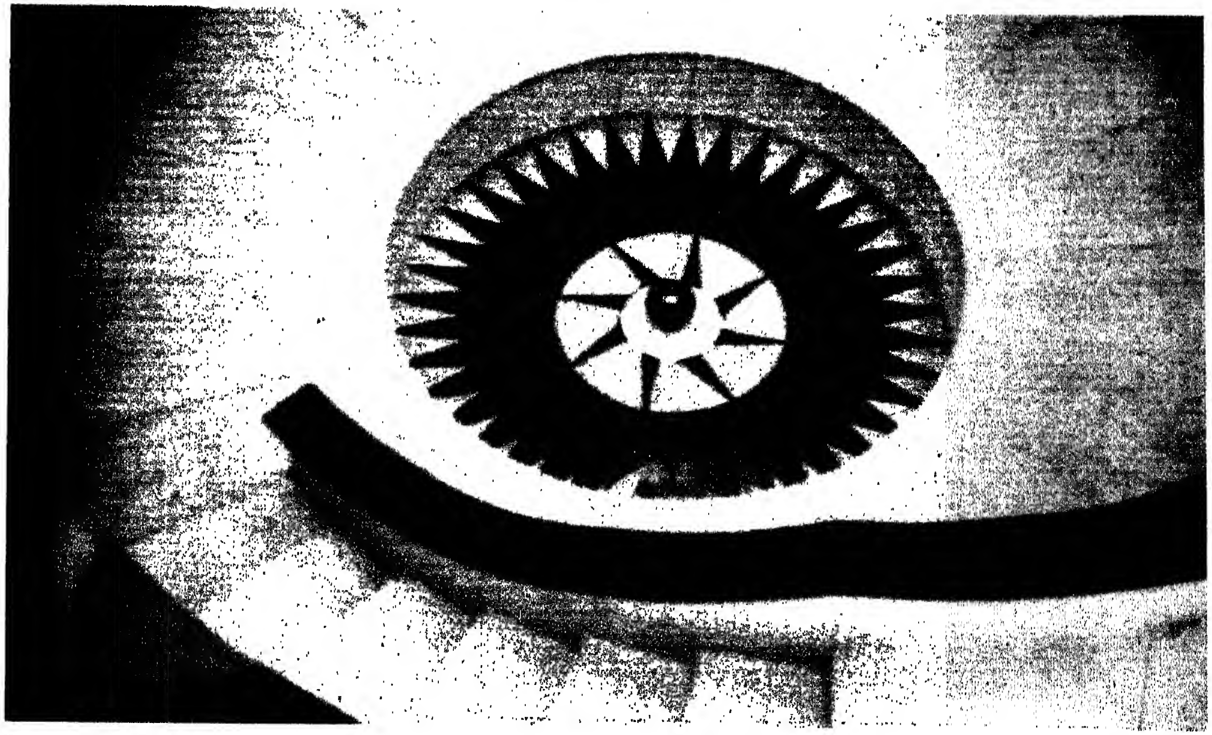
C9. The sky at 34.5 MHz, as observed from Gauribidanur. The region shown is within ± 50° of zenith angle, and is smoothed to a resolution of 2° to highlight the large scale features. The numbers next to the colour key indicate the equivalent brightness temperature of the sky in units of 1000 K.



C10. Huge plastic balloons with parachute and scientific payload, ready for launch.



C11. Indian remote sensing satellite, IRS-P2, that was launched by PSLV-D2 on 24 October 1994.



C12. Inter-University Centre for Astronomy and Astrophysics : The Foucault pendulum in the Aryabhata building.

FACILITIES

Decametre-wave Radio Telescope

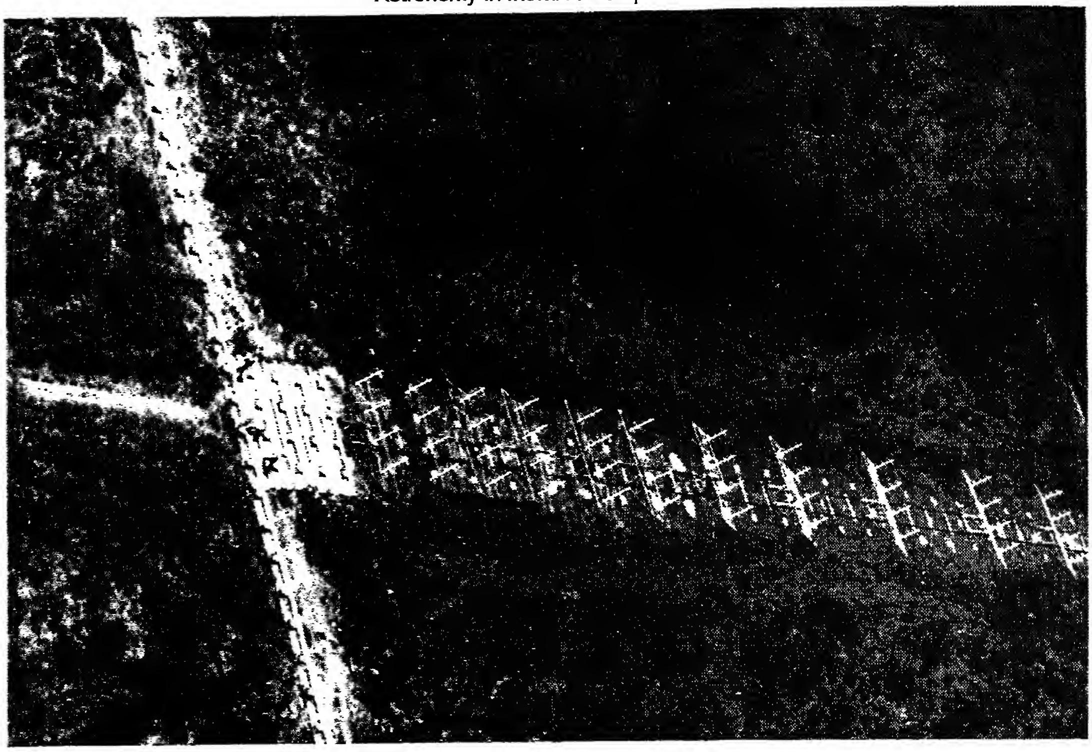
The Institute has set up a decametre-wave radio telescope at Gauribidanur, near Bangalore, jointly with the Indian Institute of Astrophysics.This array consists of 1000 dipoles arranged in the form of letter T.The east-west arm is 1.4 km long and contains 640 dipoles, whereas the north-south arm, with 360 dipoles, is 0.45 km long. At the operating frequency of 34.5MHz this telescope has an angular resolution of 26 arcmin x 42 arcmin and a collecting area of 18,000m^2 at zenith. This telescope has been used to study radio emission from the sun, Jupiter, pulsars and other radio sources of various kinds in our Galaxy and in external galaxies etc.

Millimetre-wave Telescope

The Institute has set up a millimetre-wave telescope of 10.4m diameter within its campus. The front-end receiver is a dual-polarization cooled Schottky receiver operating at 20° K and tunable over a frequency range between 80-115GHz. Both beam switching and frequency switching facilities are available. The spectrometers available include (i) 256 channel filter bank with 250kHz resolution, (ii) 128 channel filter bank with 50kHz resolution, (iii) 128 channel filter bank with 1 MHz resolution, and (iv) acousto-optic spectrometers with 40MHz, 120MHz and 400MHz bandwidths respectively.

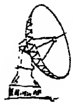
Mauritius Radio Telescope

The Institute, in collaboration with the University of Mauritius and the Indian Institute of Astrophysics, is in the process of setting up an aperture synthesis telescope at Bras D'eau (long. 57°E, lat, 20°N) in north-east Mauritius. It is a 'T' array with a 2 km long east-west arm and a 1 km long north-south arm. The east-west arm has 1024 fixed helical antennas with an inter-element spacing of 2m. The 1 km long north-south arm will be synthesized by observations spread over 64 days using 32 trolleys on rails with four helices mounted on each trolley. The main objectives of this telescope will be to (i) map the galactic plane at 150MHz with a sensitivity of 150mJy and a resolution of 4 arcmin x 4 arcmin at zenith; (ii) produce a catalogue of point sources in the declination range -10° to -70° which will be the southern sky survey equivalent of the 6C sky survey; (iii) study pulsars; (iv) study recombination lines; and (v) study variability of extragalactic sources.



16. An aerial view of the Mauritius Radio Telescope.

17. Interplanetary scintillation telescope at Ahmedabad.



Physical Research Laboratory, Ahmedabad

At PRL, which has optical as well as radio astronomical facilities, studies are being carried out to estimate the density deviation and the scale size of the plasma irregularities in the interplanetary medium, and to estimate the solar wind velocity by comparing the spatial fluctuations of the pattern as it drifts across. This will be accomplished by a combination of three radio telescopes at Thaltej in Ahmedabad, Rajkot and Bhavnagar which form a triangle of about 200km baseline. The telescope at Ahmedabad has an aperture of 20,000m^2 and the one at Rajkot 5,000m^2. The Bhavnagar telescope (5,000m^2) is likely to be operational by the year end. The selection of the sources is being carried out by a set of 32 beams formed in the north-south direction by a passive device called Butler Matrix.

Space astronomy

India's space programme was launched rather modestly in 1948 when bunches of small rubber balloons were flown by TIFR from Delhi for cosmic ray studies. Another institute with interest in cosmic rays was the Physical Research Laboratory, Ahmedabad, (PRL) set up by Vikram Ambalal Sarabhai (1919-71) in November 1947. Over the years, the TIFR stream has concentrated on pure astronomical studies from space, while the PRL stream has led to the Indian space rocket programme.

Tata Institute of Fundamental Research, Bombay

During 1948-54, clusters of rubber balloons carrying small payloads were flown to heights of 25-30km from Madras, Bangalore, Delhi, and Srinagar. Plastic balloons were introduced in 1955. Since 1969 all flights have been launched from Maula Ali, Hyderabad, where an integrated scientific balloon facility was set up (since renamed TIFR National Balloon Facility). In the early years, special materials were developed to cope with the characteristics of the troposphere at equatorial latitudes which is much colder than at higher latitudes. It was but natural that the expertise gained in the field of scientific ballooning from cosmic ray studies would be enlarged and applied to the newly opening vistas in astronomy. Since 1956 a total of 419 balloon flights have been launched. During the last six years, there have been 34 major flights, devoted to X-ray astronomy, infrared astronomy, and various areas of atmospheric sciences. The balloon facility has also been used by other national institutions. In addition, it has participated in international collaborative programmes.

Following the American discovery of the first extra-solar X-ray source Sco X-1 in 1962, an X-ray telescope was flown on 16 April 1968. In 1973 TIFR began its programme of balloon-borne far-infrared astronomy, with a simple 30cm telescope, which provided a field of view of about 8 arcmin. It was followed by a 75cm telescope with a better pointing accuracy and a smaller field of about 3 arcmin. On its loss at the end of a flight in 1980, a 100cm telescope was pressed into service in November 1983. In addition to balloons, rockets have also been used for X-ray studies (see the following).

FUTURE PLANS

After a few more balloon flights of the 100cm telescope with the two-band photometer, it is planned to improve the set up in all aspects. The aperture of the telescope will be increased, and, the orientation capability as well as the photometry improved with a view to studying individual objects in detail beyond the wavelengths covered by IRAS.

Indian Space Research Organization, Bangalore

In 1948, on Bhabha's initiative, an Atomic Energy Commission was set up, followed by the establishment of the Department of Atomic Energy (DAE) in 1954. In 1962, DAE set up the Indian National Committee for Space Research (INCOSPAR) with Sarabhai as its chairman. The next year, an Equatorial Rocket Launching Station was established at Thumba near Thiruvananthapuram (Trivandrum) and the magnetic equator. India's first, two-stage, sounding rocket went up on 21 November 1963. (In the 1970s two more launch stations were established at Shriharikota and Balasore). On Bhabha's death in a plane crash in January 1966, Sarabhai was appointed chairman of DAE. Space research activity increased rapidly at Ahmedabad as well as Thumba. In 1969, Indian Space Research Organization (ISRO) was set up to `carry on national programmes of space research and its applications for the social and economic development of the country'. Finally in 1972 there came the establishment of a Space Commission and a full-fledged Department of Space. (The headquarters are at Bangalore.)

Thumba's proximity to the magnetic equator makes it especially advantaegeous for studying cosmic X-ray sources. The first X-ray astronomy payload was launched on 22 January 1973 using a pin stabilized Centaur II A rocket. The payload reached a height of about 165 km. It was followed by another successful launch on 27 October 1976. Finally on 24 June 1979, Rohini 560 rocket was used to launch from Shriharikota a bigger and more sophisticated payload, which reached a height of about 330 km. The programme was discontinued in the 1980s.

18. Homi Bhabha along with A.S.Rao in the process of releasing a rubber balloon for cosmic ray studies, from Central College grounds, Bangalore, ca 1948.

On 4 May 1994, fourth developmental Augmented Satellite Launch Vehicle, (ASLV-D4), fired from Shriharikota, successfully placed the Stretched Rohini Satellite Series C2 (SROSS-C2) in a low earth orbit. The 113 kg satellite is in an elliptical orbit of 437 km perigee and 938 km apogee at an inclination of 46 deg. It carries two payloads: a gamma-ray burst detector; and a retarding potential analyser to measure densities, temperatures and flux characteristics of ionospheric ions and electrons.

On 15 October 1994 the Polar Satellite Launch Vehicle PSLV-D2, fired from Shriharikota, placed the 870 kg Indian Remote Sensing Satellite IRS-P2 in a near-polar sun-synchronous orbit at an altitude of 820 km and inclination 98.6°.

FUTURE PLANS

With the successful launch of PSLV, the ASLV series is being discontinued and a new Rs.250 crore project undertaken to develop three vehicles of a new series: PSLV-C1, C2 and C3. In addition development work is continuing for launching Indian National Satellite (INSAT) for communication and meteorology.

The Geo-stationary Satellite Launch Vehicle (GSLV) being developed by ISRO will have the capability to place a 2.4 ton spacecraft into geo-stationary transfer orbit. It could also be used to place a smaller, 1 to 1.5 ton, spacecraft into a planetary escape trajectory. Once the launch technologies are perfected, more attention will be paid to developing payloads including astronomical instrumentation.

Gamma-ray astronomy from ground

Cosmic gamma rays are the most energetic electromagnetic radiation produced by nature. These rays cannot reach the surface of the earth. A general gamma-ray view of the universe therefore comes from detectors aboard satellites. Very high energy component of this radiation (energies above 10^{12} eV) can be detected on ground, not directly but through the visible Cherenkov radiation it produces in the earth's atmosphere. Gamma - ray astronomy in India came about as a sequel to cosmic ray studies. There are at present, two facilities in this area : one under Bhabha Atomic Research Centre (BARC), the other under Tata Institute of Fundamental Research (TIFR).

Nuclear and High - Altitude Research Laboratories
(Bhabha Atomic Research Centre, Bombay)

In 1965, Department of Atomic Energy set up a High Altitude Research Laboratory at the Himalayan resort of Gulmarg (long. 74° 24′ E, lat, 34°03′ N, alt. 2743m) for carrying out cosmic ray studies. In 1985, a gamma - ray telescope was set up at Gulmarg. Over the years, research has been carried out from Gulmarg in a range of other fields also: radio astronomy, solar physics, atmospheric and ionospheric physics, environmental and botanical sciences, geomagnetism and aeronomy. In the meantime, in 1973, Nuclear Research Laboratory was established at Srinagar. A new unit of this laboratory has recently started operations from Bombay and detectors will also be set up on Gurushikhar.

FACILITIES

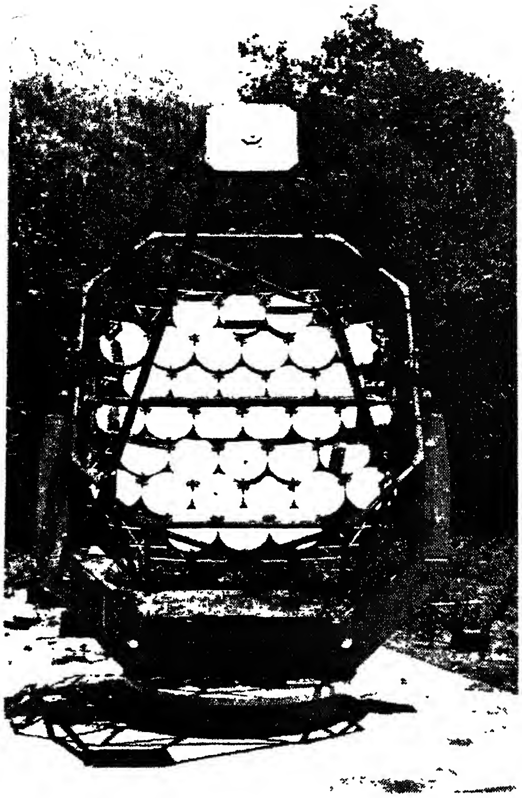
The Gulmarg gamma - ray telescope system consists of seven equitorially mounted back coated parabolic glass mirrors, each of 90 cm aperture and 40 cm focus. The telescope proper consists of six mirrors arranged in two rows; each row acts as an independent detector bank. Each mirror in the bank is viewed from its focus by a fast photomultiplier tube through an optical filter having 90% peak transmission at 4000A and a full width at at half maximum of 500A. The seventh mirror is used to monitor the night sky for any variation in the atmospheric transparency conditions during the course of observations.

The telescope was successfully used for detecting short time-scale gamma - ray bursts from various non-solar galactic sources. The operations however had to be suspended in 1990.

FUTURE PLANS

In 1990 an extensive site survey programme was launched. INSAT-ID satellite cloud imagery in the infrared and visible bands over the five-year period 1986-91 was analysed. It turned out that the mean percentage per year of clear nights was highest at Gurushikhar, Mt Abu (65%) followed by Pachmarhi (52%), Naini Tal (49%), Solan (42%), Jammu (38%), and Gulmarg (22%). On the basis of this plus other data, it was decided to set up a Cherenkov type gamma-ray telescope at Gurushikhar, next to the infrared observatory of the Physical Research Laboratory, Ahmedabad. The plans are as follows.

To start with, two high - sensitivity telescopes, TACTIC and MYSTIQUE are being set up to observe in the energy range 0.2 Te V to 1 Pe V. TACTIC would comprise altazimuth - mounted optical reflectors of area 40 m^2. It would be the first imaging gamma - ray telescope



19. The imaging unit of the TACTIC gamma-ray telescope under test at the Bhabha Atomic Research Centre, Bombay.

developed in the country. MYSTIQUE would involve an array of 100 large - area, wide - angle Cherenkov light detectors, spread over an area 0.4 km^2.

In addition to studying gamma rays, these experiments can be deployed for other studies: Charge composition of ultra - high energy cosmic rays ; muon spectrum, which is important from the point of view of solar neutrino problem ; and search for Te V neutrinos and nuclearites, which are SUSY dark-matter particle candidates.

High Energy Gamma - Ray Observatory, Pachmarhi
(Tata Institute of Fundamental Research)

In 1969, TIFR scientists set up a small gamma - ray telescope at Udhagamandalam. It consisted of just two 0.9 m diameter parabolic mirrors borrowed from the Indian navy. In 1976, 12 more similar mirrors were added to the array. Further augmentation came a few years later when there were added eight large, 1.5m diameter, parabolic mirrors loaned from Smithsonian Astrophysical Observatory, U.S.A. In 1986, the facility was shifted to Pachmarhi (long 78°26 E′, lat. 22° 28′, alt. 1050 m).

FACILITIES

Pachmarhi Atmospheric Cherenkov Telescope now consists of a total of 46 mirrors, arranged as the banks of steerable, equatorially mounted parabolic mirrors. Of these two banks consist of seven mirrors, each of 0.85 m diameter. Four banks contain four mirrors, again 0.85 m in diamater. The remaining eight banks consist of two mirrors, 0.9 m and 1.5 m diamater. For the last two years the telescope deployed at Pachmarhi has a symmetric array of 12 banks permitting lateral distribution of Cherenkov light.

FUTURE PLANS

Plans are afoot to fabricate about 200 mirrors of 0.85 m diameter. These mirrors will be used to form a symmetrical array of 25 individual telescopes each consisting of seven mirrors on a single steerable mount. This would enable exploitation of a technique already proven at Pachmarhi and to detect lower and lower energy gamma rays. The array is expected to be ready in about 18 months time.

University sector

During the British period, universities were the only forum available to the Indians for carrying out research. Pioneering researchers in theoretical astrophysics and relativity were all university teachers. In spite of this, astronomy and astrophysics did not become an integral part of general university education. Many universities no doubt offered astronomy as an optional course for mathematics students at the graduate level, but this astronomy hardly went beyond spherical trigonometry. Furthermore, although Nizamiah Observatory was attached to the Osmania University as early as 1919, the arrangement was administrative rather than pedagogical. It is only in the late 1950s that attempts were made to bring modern astronomy to the universities. Osmania University opened a department of astronomy in 1959. In 1962 Delhi

University formally renamed its physics department as department of physics and astrophysics and even offered an M.Sc. degree in astrophysics for a few years. Years later, in 1978, Punjabi University, Patiala, opened a department of astronomy and space sciences and furnished it with a 50cm aperture telescope. Osmania and Punjabi remain the only two universities with separate astronomy departments, but now at least a dozen university departments offer astronomy and astrophysics as an option to their physics students. Many teachers in physics and mathemetics departments are engaged in research in astronomical and related sciences.

Indian universities, numbering more than 150, are generally beset with a number of problems including acute shortage of funds. With a view to upgrading the research and teaching programmes in the universities, the University Grants Commission of the government of India decided to set up inter-university centres in specified fields.

Inter - University Centre for Astronomy and Astrophysics, Pune

Inter-University Centre for Astronomy and Astrophysics (IUCAA) was established in 1988 at Pune. IUCAA is a research centre in its own right with a small core faculty of researchers - cum - educators. IUCAA seeks to help the universities in a number of ways. It helps design of a vigorous academic programme and train teachers for it. With a view to helping the university and college teachers and research students feel at home with astronomical instruments, IUCAA invites them to participate in specific projects in its laboratories. The IUCAA instrumentation laboratory has begun with a do-it-yourself project of making an automated telescope. The project involves the users from universities and colleges as active participants in telescope making.

Helping the teachers in their research programme is an important item on the IUCAA's agenda. Towards this end it runs an associates' programme, which permits the associates to visit the Centre for long and short durations so that they can carry out their own work and interact with other visiting scientists or with the faculty. The Centre also seeks to encourage and help the university faculty members in carrying out their research at other centres. In this context it is no coincidence that both IUCAA and the GMRT project are located in the Poona University campus. Apart from organizing appropriate schools and refresher courses for teachers and students, IUCAA also participates in science popularization through interaction with amateur astronomers, young students and general public.

IUCAA boasts of what may soon become the best working library in the country, which attracts users from all over India. The electronic mail and remote logging on computers in a worldwide network have broken national barriers to bring the Indian community of astronomers in close contact with their international counterparts.

FUTURE PLANS

With a core faculty of ten, a comparable number of post-doctoral fellows 45 associates and a large number of visiting scientists, IUCAA has currently attained about half its optimal size. It is aspiring to be the main hub of astronomical activity in the country in the university sector.

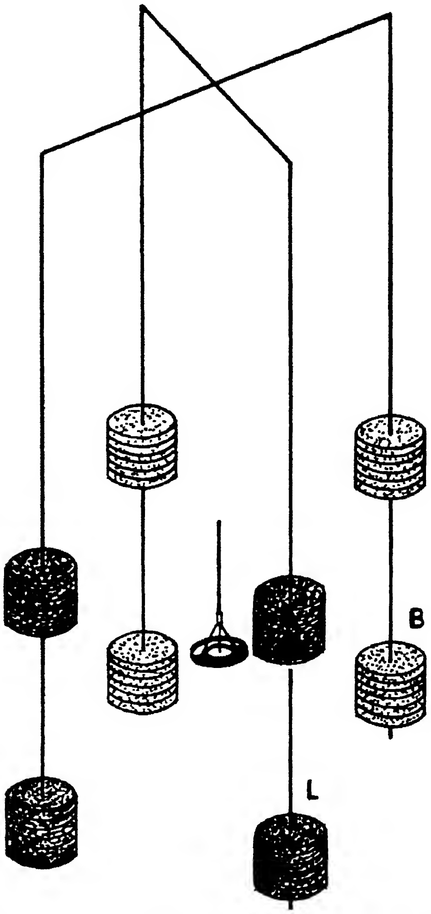
To make the associateship programme work, the universities must come to look on IUCAA as their own field station so that a staff member who has come to use its facilities is treated as on duty. IUCAA's overtures to university departments for strengthening astronomy and astrophysics will need to be reciprocated and taken advantage of.

Experimental gravitation

Experimental studies of gravitation and feebler forces at Gauribidanur

A high-precision torsion balance has been set up to study the various fundamental properties of gravitation. The experiment is located at Gauribidanur in a seismologically quiet arid region near Bangalore, and is jointly run by Tata Institute of Fundamental Research and Indian Institute of Astrophysics. The aim of the programme is to (i) test the principle of equivalence of inertial and gravitational masses to an accuracy higher than 10^{-14}, and (ii) to search for hitherto unknown forces weaker then gravity.

The experimental arrangement is as follows. Two half-rings, made of copper and of lead, each about 8.5cm in radius and weighing 700g, are joined together to make a single ring. A tungsten fibre, 250cm long and 105 micron in diameter, is used to suspend the ring, keeping its plane horizontal.The chamber containing the equipment is then evacuated to a pressure below 10^{-8} Torr. To shield the balance from variations of temperature, the whole arrangement is installed in a specially constructed 25m deep well. Inside the well, four lead masses about 160kg each are suspended in two columns from the two adjacent arms of a plus-shaped truss, that can be rotated. These lead masses are counter-balanced by a similar set of brass masses which are



20. A schematic drawing showing the torsion balance at Gauribidanur. In the centre is the copper-lead ring surrounded by brass (B) and lead (L) weights.

suspended from diagonally opposite points of the truss.The aim of the experiment is to study the coupling of any force field generated by these masses with the compositional dipole of the ring, by measuring its angular deflection using a sensitive autocollimator. In particular, the experiment sought proof, if any, of the existence of a fifth force that couples to the nuclear isospin N-Z, where N is the number of neutrons and Z of protons. The Gauribidanur experiment became operational in 1987. The results were essentially negative. Any such force with a range greater than about 1m must have a coupling strength $< 5 \times 10^{-5}$ in units of gravity per atomic mass unit.

The experimental set up is currently being modified for improved immunity from noise sources. A new set of experiments is under way to test the principle of equivalence at the level 10^{-13}, within the next six months. It is proposed to achieve a sensitivity of 10^{-14} in the following three years.

3

Research highlights

When India entered the second half of the present century, it could boast of only two observatories and astronomical manpower of around twenty. Over the years there has been an all - round increase in astronomical activity. This chapter describes the current state of research and gives a brief summary of the important results that have been obtained. Both observational and theoretical works are described together in broadly classified subject areas.

The sun

The Kodaikanal Observatory of the Indian Institute of Astrophysics (IIA) and the Udaipur Solar Observatory (USO) are exclusively devoted to the studies of the sun. Solar studies form a major part of activity at Naini Tal and figure in the work of other observatories

The chief highlight of the Kodaikanal Observatory's work has been the 1909 discovery of the Evershed effect, viz., the outward radial flow of gases in sunspots. Later work revealed that there is a reverse flow at chromospheric heights. Over the years, the Observatory has obtained a long stretch of white-light solar pictures and spectroheliograms. The Ca II K pictures tell us about the upper chromosphere, Hα pictures about the lower chromosphere, while white-light pictures provide information about sunspots. The Kodaikanal database has been used to discover a number of significant correlations among solar phenomena. At the same time, high-resolution spectra obtained with the tunnel telescope have been analysed to yield important results.

It has been shown from Kodaikanal that time variation of total plage area on the visible hemisphere of the sun carries the definite signature of solar rotation. This correlation provides a convenient method for estimating the rotation of stars which have chromospheres. The solar chromospheric rotation rate has been found to show variations on the time scales of two, seven, and 11 years. Studies have been initiated to obtain information on solar rotation from precise

measurements of the old sunspot data. The Hα data for 1905-82 have been used by the IIA scientists to investigate the global properties of large-scale magnetic fields. It has been shown that the fields migrate towards the poles with a variable velocity of up to 30m s^{-1} depending on the phase of the solar cycle. It has been found that there is a correlation between Ca II K emission and the magnetic field strength in the plages. This correlation can be used for estimating the magnetic fields of stars from their Ca II K spectra. It has been shown that a day or two prior to the occurrence of a flare, there occurs a change in the orientation of the Hα filament.

Using fine-quality solar Ca II K spectra, IIA scientists have concluded that the Wilson-Bappu relationship between K emission line widths and the absolute magnitude of stars mostly arises due to the elements that make up the quiet atmosphere. This work suggests that the stars which deviate the most from the Wilson-Bappu relationship are the best candidates for studying stellar activity cycles! Ca II K line profiles of the sun obtained in integrated light have been found to vary with the phase of the solar cycle. This indicates that the sun is a variable star. It has been found that the size of the Ca II K (supergranular) network is a function of the solar cycle : The cells are smaller at the solar maximum than at the minimum. It has also been shown that within the bright supergranular boundaries there exist dark regions of 4000-6000 km size. These regions are characterized by relatively large downflow velocities of 5-8 km s^{-1} compared to neighbouring horizontal velocities of about 0.5 km s^{-1}.

Detailed studies have been carried out at Kodaikanal of velocity and intensity fluctuations in selected solar spectral lines, with special reference to five-minute oscillations. It has been found that intensity fluctuations are coherent over scale lengths of about 10000 km on solar surface. The newly built spectropolarimeter has recently been used to obtain a large number of spectra in quick succession. This facility promises to provide new results in areas such as sunspot seismology, speckle reconstruction of solar features, and time evolution of solar flares.

USO is a participant in the international programme of Global Oscillation Network Group (GONG). Udaipur has been selected as one of the six sites distributed around the globe for making solar velocity oscillation observation for helioseismology. The Observatory has taken part in a number of international programmes, e.g., solar maximum year, solar maximum mission satellite, Flare 22/Max 91.

From a large collection of chromospheric observations made from Udaipur, a photographic atlas of some typical examples of chromospheric activity has been published. The dynamics and evolution of several solar flares and mass ejections have been studied. From a study of proper motion of sunspots, it has been possible to estimate the build-up and release of energy in flares.

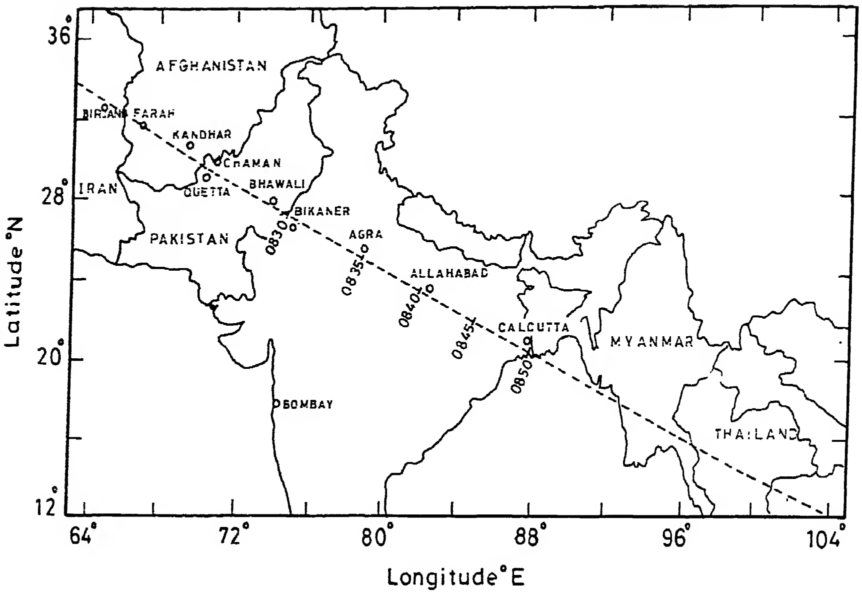
Modelling of magnetic field structure in post -flare loops and flaring arches and study of the stability of dark Hα filaments on the disc are being carried out.

Patrolling of the sun is done regularly at Uttar Pradesh State Observatory, Naini Tal (UPSO) to record and analyse flares, surges, prominences and other active features. The relationship of the morphology of the active features with mass motions and prevalent magnetic fields is sought. Correlations among the optical, microwave, X-ray emmisions and sudden ionospheric disturbances have been investigated. The existence of active longitudes on the sun has been postulated. Relationships between coronal holes, coronal mass ejections and solar flares have also been studied.

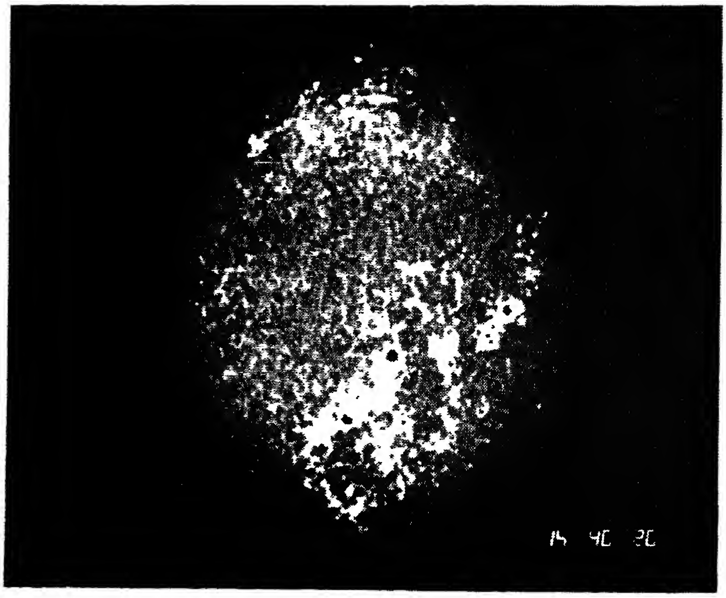
The sun has been studied at decametre radio waves using the Gauribidanur telescope. Maps have been produced of continuum emmision from the quiet sun and the active regions. The compound grating interferometer has been used to make high resolution (3 arcmin) one - dimensional scans of the sun. These scans have in turn been used to measure the varitions in the east - west diameter of the undisturbed sun, active regions and coronal holes.

Expeditions to observe total solar eclipses have been an important part of work at IIA. The 1970 total solar eclipse revealed the rather unexpected presence of Hα emission in the solar corona. Multislit spectroscopy of the solar corona carried out during the successive 1980 and 1983 total solar eclipses has thrown significant light on the physical processes in the corona. (i) It has been shown that ions have larger random motions in closed coronal loops than in the open. (ii) At the time of increased solar activity turbulence shows a significant increase. (iii) The mechanism for excitation of ions in the corona is not uniform, with collisional excitation dominating near the solar limb and radiative excitation in farther regions. In addition, photometric and polarization measurements of the coronal structure have often been carried out.

IIA results support the view that there are no large - scale mass motions in the solar corona. On the other hand coronal interferograms obtained during the 1980 and 1983 eclipses by scientists from the Physical Research Laboratory, Ahmedabad, (PRL) have been interpreted as evidence for the existence of large mass motions, especially during the active solar phase. The passage of the path of totality of the total solar eclipse of 16 February 1980 over Japal-Rangapur Observatory (JRO) offered a unique opportunity to study the corona, using a large telescope. JRO astronomers carried out a two-colour polarimetric study of the corona. Besides giving electron density and temperature in the corona it confirmed the dependence of the brightness of the F corona on wavelength. Variation of the 3cm radiation from the sun during eclipse was also studied.



21. The path of totality of the total solar eclipse of 24 October 1995.



22. The sun photographed in the light of the K line of ionized calcium from Maitri station, Antarctica, 9 January 1990.

A three-member team from IIA observed the total solar eclipse of 3 November 1994 from Putre in north Chile. More important from the Indian point of view will be the total solar eclipse of 24 October 1995, which will be seen from a stretch of land extending from Iran in the west to Kampuchea in the east.The path of totality will pass through the states of Rajasthan, Uttar Pradesh, Bihar and West Bengal. A number of international scientific teams are expected to visit north India for the eclipse.

The continent of Antarctica provides a round-the-clock view of the sun. In the local summer of December 1989-March 1990, a three-member team from IIA and UPSO set up a small observatory at the Maitri station. A combination of a polar heliostat and a 10 cm aperture, f/30, objective lens was used to obtain pictures of the sun in the light of the Ca II K line. Uninterrupted data extending over as long as 106 hours have shown that the average life time of a supergranular cell is about 22 hours. It has been shown for the first time that there is a correlation between lifetime and size of a cell in the sense that larger cells live longer. Also, cells associated with remnant magnetic fields live longer than those of comparable size in field-free regions.

Scientists at the Tata Institute of Fundamental Research, Bombay (TIFR) have taken part in worldwide efforts to understand the deep interior of the sun. These efforts include trying to explain the observed low flux of solar neutrinos and modelling the five-minute oscillations of the solar surface. Theoretical aspects of various solar phenomena are being studied at IIA, TIFR, National Physical Laboratory, New Delhi (NPL) and elsewhere. Theoretical investigations into the existence of a number of molecular species (diatomic, triatomic and ionic) have been carried out at UPSO. Molecular constants such as oscillator strengths, dissociation energies, Frank-Condon factors and partition functions for some molecules have been calculated. Turbulent velocity for the solar photosphere has been determined using centre-to-limb CH line profile variations.

Extensive studies at the National Centre for Radio Astrophysics, Pune (NCRA) have shown that the spectrum of turbulence in the solar wind is best described by a power law with an 'inner scale' rather than by a Gaussian. This makes it possible to estimate the solar wind velocity from single-station observations alone. Velocities thus estimated are in close agreement with those derived from the conventional three-station measurements. This powerful technique is currently being used to study transients in the solar wind and the dependence of solar wind velocity on heliographic latitude and on the solar cycle.

Solar system studies

A sky survey using the 45 cm Schmidt telescope was begun at the Vainu Bappu Observatory, Kavalur (VBO) in 1987 for the search of asteroids and other minor bodies in the solar system. A new asteroid numbered 4130 was discovered on 17 February 1988. This asteroid was later named Ramanujan after the Indian mathematical genius Srinivasa Ramanujan.

Observations of occultation by solar system bodies have been carried out from VBO for almost a quarter century now and have yielded important results. Observations made at VBO contributed to the 1973 discovery of a thin atmosphere on the Jovian satellite Ganymede. Rings around the planet Uranus were discovered in 1977. Evidence for the suspected existence of an outer ring around Saturn was obtained in 1984. Mutual occultations of the Jovian satellites have been regularly observed since 1985. Analysis of these events has yielded improved ephemerides of the satellites and shown that the tides raised by Jupiter cause deceleration of satellite Io's mean motion. Mutual events of the Pluto - Charon system and lunar occultation of stars in optical and infrared for high angular resolution measurements are being regularly observed from VBO. From balloon-borne observations made by TIFR scientists on 10 December 1980, a reliable value of 97 ±3.5K was obtained for the brightness temperature of Saturn's disc at 76-116μm. It was concluded that the emissivity of the rings decreases substantially at far-infrared wavelengths.

Theoretical work on planetary atmospheres has been carried out at Osmania University, Hyderabad. Absorption and polarization line profiles were calculated for a semi-infinite planetary atmosphere in the integrated light as well as along the intensity equator and the mirror meridian for the Rayleigh phase matrix. Comparison with the observation of Venus revealed that the continuum originates in a deeper layer where Mie scattering predominates, while the lines arise in a higher layer where Rayleigh scattering prevails. A new definition of the effective depth of line formation was given which explains the variation of the equivalent width over the disc, its inverse dependence on line strength and the phase effect in integrated light. H-functions were calculated for 35 anisotropic phase functions and used for studying the correlation between the phase function and the phase effect of the equivalent width.

Comets have received considerable attention. Imaging, photometric, spectroscopic, polarimetric and other observations of a number of comets have been carried out at various centres. During the occultation of the radio source 2025-15 by comet Kohoutek in January 1975, Ooty Radio Telescope was used to observe scintillations through the plasma tail. Halley's comet was observed in 1985 - 86 by various observatories as part of the International Halley Watch Programme. PRL scientists observed that comet Austin (1990) was richer in fine particles than

comet Halley. Imaging of the nucleus of comet Swift - Tultle (1992) at VBO showed that it had a rotation period of about 3 days. Multi-fragment crash of comet (1993e) Shoemaker-Levy 9 into Jupiter was observed during 16-22 July 1994 from Kavalur, Japal-Rangapur and Bangalore at optical, infrared and radio frequencies. Observing with the 10.4m aperture millimetre-wave telescope, RRI astronomers recorded that every time a cometary fragment hit Jupiter, its radio emission at 86GHz went up substantially for a short time. An intense infrared flash in the H-band caused by the impact of fragment S was detected on 21 July 1994 through the 0.75m aperture telescope at Kavalur.

Meteoric activity at the Hyderabad latitude has been studied using a 50 MHz continuous-wave meteor-radar during 1983-92 at the JRO. The group working at PRL came up with valuable evidence from the analysis of meteoritic data on the early history of the solar system including a signature of the active early phase of the sun and isotopic records of ambient stellar nucleosynthesis. Significant results have been obtained on the total electron content of the ionosphere and the amplitude scintillations of the satellite radio beacon signals recorded at Hyderabad. Ionospheric irregularities have been studied at JRO by recording the Faraday rotation angles, using the three-station method, under and the International Atmospheric Programme. An important result was obtained in 1969 on the effect of celestial X-ray sources on earth's atmosphere while recording field strengths at Ahmedabad of 164 kHz radio waves transmitted from Tashkent. It was noted that a pronounced minimum recurred night after night during April-July. This phenomenon was attributed to increased ionization in the lower D-region of the ionosphere due to the transit of SCO - 1 across 71° E, the one-hop reflexion meridian of radio waves from Tashkent to Ahmedabad.

Stars and the Galaxy

The Milky Way Galaxy and its constituents have been extensively studied from ground - based observatories.

Classification of Am stars on the basis of their MK spectral morphology has been carried out using the Meinel spectrograph at the Nasmyth focus of the JRO 1.2m telescope. As many as 100 spectra of Am stars and MK standards were obtained at 66Å mm^{-1}, and their digital profiles used for classification. Using spectra at a higher dispersion of 33 A mm^{-1}, Osmania astronomers have detected a phase-modulated spectral line variation in some of these Am stars.

A study of chemical composition of classical Cepheids and related chemical inhomogeneities of the Galactic disc was carried out from VBO. The [Fe/H] index of nearly two dozen Cepheids was derived. The places of formation of the Cepheids were determined by

numerically integrating their orbits backwards in time under the influence of the axisymmetric and spiral - like gravitational field of the Galaxy. A steeper variation of [Fe/H] accross the Sagittarius and Perseus arms was encountered as distinct from the overall variation of [Fe/H] across the disc. Spectroscopic work on Cepheids has continued and chemical abundances in a number of them have been derived with the help of synthetic spectra.

Photometry and polarimetry of a number of hydrogen - deficient stars and carbon stars in UBVRI and JHKL bands have been done at VBO. Several R CrB variables have been followed in their deep minima and also during the recovery phase. Spectroscopy in the visible region has been combined with extensive IUE data to determine their atmospheric properties, to obtain information on the circumstellar environments of these stars, and to estimate their chemical composition.

High dispersion coude spectra of several supergiants of late G and early K spectral classes have been obtained at VBO. The blue asymmetry of the Hα line profiles in these spectra was attributed to the occurrence of chromospheric expansion of these stars eventually leading to mass loss. Detailed radiative transfer models were computed to match the Hα equivalent widths obtaining in the process the density distribution in the chromosphere as well as the mass loss rates. The infrared Ca II triplet lines have been surveyed in a large sample of dwarfs, subgiants, giants and supergiants with the aid of high dispersion coude spectra.. Sensitivity of the equivalent widths of these lines to gravity, effective temperature and metallicity has been investigated. These results are of great value in the studies of stellar populations in galaxies.

Observations of SiO masers in red supergiants, in particular the Mira variables, has been a major programme with the Millimetre-wave Telescope at the Raman Research Institute (RRI). The study of cometary globules and their kinematics near OB associations (such as the Gum Nebula, Orion, Cepheus, etc.) is one of the major on-going programmes with this telescope.

Polarimetric studies of individual stars have been carried out at VBO. Of particular interest have been the post-asymptotic giant branch stars with circumstellar dust shells. The RV Tauri star AR Pup has been found to show very high linear polarization, $\approx$ 14%, in the U band. This is the highest polarization observed for a single star not associated with a known nebulosity. In addition, pre-main sequence stars have been studied polarimetrically. Polarization maps of young OB associations and molecular clouds have also been obtained from VBO by IIA astronomers.

A detailed spectroscopic study of the Scoropio-Centaurus association was undertaken at VBO. Rotational velocities of the members of the association down to 8.5 mag were obtained. The study showed that the stars of the upper Scorpius group were fast rotators as distinct from

those of the Centaurus-Lupus and lower Centaurus-Crux subsystems. The faster rotation of the upper Scropius group was attributed to either accretion effects or to effects of the interaction with the surrounding interstellar medium that might have partially destroyed the randomness of orientation. The data on Scorpio-Centaurus association were combined with the data on the other clusters to investigate the effects of rotation on colour indices of stars. A zero-rotation zero-age main sequence was determined following a conventional cluster fitting procedure. A possible solution to the blue straggler phenomenon in open clusters in the spectral type domain of A stars was suggested in which the anomalous position of these stars could be completely accounted for in terms of their slow rotation.

Star clusters have been studied at VBO, for their intrinsic properties, as testing laboratories of the theory of stellar evolution and from the point of view of galactic studies to discern if they showed a spiral pattern. A few of them containing astrophysically interesting objects like planetary nebulae have been observed in great detail to faint magnitudes. Star clusters have also been utilised to calibarate and standardize the photometry done at VBO.

An important contribution from VBO has been a detailed photometric study of the globular cluster Omega Centauri. Photoelectric scans were made along the major and minor axes in UBVRI. In addition equidensity contours were obtained from direct photographs taken with an f/6 camera in BVI. Using these, the change of ellipticity from the centre to the outer regions of the cluster was evaluated. A large concentration of blue stars was discovered at a distance of 2.5 to 5.5 arcmin from the centre. Their distribution was elliptical in contrast to the more spherical distribution of red stars. Blue bulges were also observed in some other globular clusters.

Using the Fabry-Perot spectrometer of PRL, IIA astronomers have carried out kinematic studies of planetary nebulae. Several bipolar nebulae and a few others with peculiar characterestics have been studied. Deep CCD imaging of planetary nebulae in and away from the emission lines has been done in an attempt to discover the undetected nuclei. Colour excess maps of many of these nebulae have been prepared using broadband imaging. Particular attention was paid to M4 - 18, prototype of a class of planetary nebulae with WC 11 type central stars. These observations were combined with IUE and IRAS data to study the properties of the star and the nebula.

Binary stars have figured prominently on the observers' agenda. The elements of Gamma Velorum determined from Kodaikanal in 1963 remained the most accurate for almost two decades. Another star that recieved a good deal of attention in the early days of VBO was Canopus. High dispersion (2.8 $A^{\circ}mm^{-1}$) plates of this star were obtained in the blue region to study the variation of its Ca II K line profile.

Photometric and spectroscopic studies of RS CVn binaries have been persued at VBO for many years. In addition to accurate period determinations, detailed modelling has been done

of the spots on a number of these stars (e.g. DM UMa, II Peg, V711 Tau). Be stars and Be X-ray binaries have been examined spectroscopically. Rapid variability in the H α line profiles in a number of them has been closely monitored. VBO has participated in the international MUSICOS campaign on some Herbig Ae/Be stars and the Delta Scuti star θ^2 Tau.

UBV photometry of eclipsing binaries and variable stars has been an ongoing research project of long standing at Naini Tal. Mass, dimensions, and physical properties have been determined for a number of eclipsing binary stars. In addition, period studies have been done for a few of them as well as for Delta Scuti, Beta CMa, and RR Lyr stars. Gravitational radiation studies of eclipsing binaries are also being carried out.

A number of eclipsing binaries have been observed in UBV passbands by Osmania University astronomers using their 1.2m telescope at Japal-Rangapur. The secondary components of the Algols have been found to be not only overluminous but also hotter for their mass, indicating partial loss of their hydrogen envelopes. Improved periods have been obtained for four binaries. Period changes were studied for 23 systems, several of which were found to be triple systems. Two new variables have been discovered from JRO. Infrared photometry of Beta Cephei, Delta Scuti, Be, and RS CVn-type stars was also carried out. Optical counterparts of some X-ray binaries have also been studied in collaboration with X-ray astronomers from TIFR.

The ISRO Satellite Centre (ISAC) has developed photometers for observing the optical counterparts of X-ray sources. These observations have been carried out in collaboration with IIA. A 14 inch aperture telescope has been installed in the ISRO campus at Bangalore. A two-channel star and sky photometer has been used to observe chromospherically active stars such as HR 1099, UX Ari, IL Hya, DM UMa, and DH Leo.

In April 1979 PRL and TIFR scientists working at Kavalur reported detection of infrared bursts from an X-ray burster. The discovery was confirmed six months later by British astronomers at Tenerife. However, no bursts have subsequently been reported from the source.

ISAC has participated in an international campaign called the Whole Earth Telescope (WET) project in which the same white dwarfs are observed using similar instrumentation from different longitudes to produce continuous coverage of data for astroseismological studies. The white dwarf PG 1159-035 has been shown to have a mass 0.586 times that of the sun, a rotation period of 1.38d, and a magnetic field of less than 6000 gauss. The twin white dwarf system AM CVn, earlier observed from Kavalur and Naini Tal, was also observed in March 1990 by the WET project. Analysis of composite data shows that the 1051s period decreases at a rate of (3.7 $\pm$0.4) 10^{-12} ss^{-1}. In the case of the single DB white dwarf GD 358, a mass of 0.6 times that of the sun is deduced. It is also suggested that the white dwarf has a very thin layer of helium.

Several classical and recurrent novae have been spectroscopically monitored from VBO during outburst and a few during quiescence. Spectroscopic differences and similarities between individual novae in outburst have been studied and the physical parameters of the ejected shell estimated. Evolution of their photospheric radii and temperature has also been monitored in a few cases. The results indicate presence of a white dwarf in the recurrent nova RS Oph for which alternative models exist that do not invoke a white dwarf. The accretion disc spectrum has been estimated from the observations of novae in quiescence and mass transfer rates and geometrical parameters of these discs derived. Spectroscopic monitoring of T CrB over a long base line in time has shown secular as well as orbital phase dependent variation in emission line strengths. Using the images of the shell of GK Per, the proper motion of individual knots have been measured and the velocity deceleration derived.Astronomers at PRL have observed dust formation as early as seven days after eruption in the fast Nova Her 1991. The result is rather surprising, because fast novae generally do not produce substantial amounts of dust. ISAC scientists have measured UBV magnitudes of nova Cygni 1992. Polarimetric studies of the peculiar symbiotic system R Aquarii by PRL scientists have suggested the existence of a precessing jet. Line profile studies in Hα give evidence of an expanding shell with a velocity of about 15 km s^{-1}.

Eight pulsars have been discovered by NCRA astronomers using ORT. Simultaneous observations of a few pulsars at 327MHz from Ooty and the Parkes Radio Telescope in Australia revealed the existence of multiple diffracting plasma screens in interstellar medium in some directions. Subsequently, an analysis of the spatial distribution of a large sample of pulsars from the Molonglo survey was used to infer the presence of a high-electron density layer about 150 light years below the plane of the Galaxy.

RRI astronomers have carried out radio observations at 12cm mainly with the Parkes interferometer, the VLA, and the 26m antenna at Hobart. The scientific objectives of these studies are (i) to understand better the velocity distribution of interstellar clouds, (ii) to get a handle on their scale sizes, and (iii) to measure distances to pulsars. An important project undertaken with the low-frequency array at Gauribidanur was an all-sky survey at 34.5MHz, using the method of one-dimensional image synthesis.

The low-frequency array at Gauribidanur was used by the RRI scientists to study the characteristics of pulsed emission from about a dozen pulsars. The study includes (i) a detailed analysis of their pulse profiles, (ii) interpulse emission, (iii) fluctuation spectra, and (iii) slow variability. Currently a deep survey is underway with the ORT.

The radio jet in the Crab nebula has been extensively investigated. A joint Indo-Japanese experiment to study the occultation of the Crab nebula by the moon in January 1975 revealed that the area emitting diffuse hard X-rays is significantly smaller than that emitting soft X-rays. This is consistent with the synchrotron origin of X-rays. Observations of CTB 80 were among the first to reveal its peculiar structure. It has a small-diameter (1 arcmin) core, extended ridges (size about 1°), X-ray point source, and an embedded pulsar of 30 cms period.

The nonthermal radio source G18.95-1.1 was shown from OSRT observations to be a shell-type supernova remnant (SNR) with a central source perhaps similar to the accreting binary SS433. It has been shown that in the case of G25.5+0.2 (which was earlier believed to be the youngest SNR in our Galaxy) the observed emission actually arises from stellar outflow from what is perhaps the most massive star in the Galaxy.

A lunar occultation of the radio source Sgr A, associated with the centre of our Galaxy, was observed by NCRA astronomers from Ooty in September 1970. With a resolution of about one arcmin at 327MHz, the observations of Sgr A provided the first details of its synchrotron radiation revealing a multicomponent structure superimposed on a halo with a diameter of about 20pc. Attempts were made to determine the abundance of deuterium by looking for the deuterium absorption line at 327.4MHz in the direction of the Galactic centre with ORT. These studies have provided the best upper limits on the D/H ratio by the radio technique.

About half a degree area of the Eta Carina nebula was mapped in 1983 by the TIFR scientists in 120-300 micron band, using a ballon-borne 100cm telescope. About 30 compact sources were detected, many of which do not find counterparts in the IRAS catalogue. Only a few per cent of the total luminosity of OB stars in the region is radiated in the far-infrared in contrast to young H II regions where most of the energy is emitted in the far-infrared. The young H II region complex W 31 was mapped in the 120-300 micron band, as well as in the radio bands. Eight new infrared sources were detected. It was also shown that the region is short of high mass, high luminosity stars. Other H II region-molecular cloud complexes with deeply embedded sources have been studied in detail.

The NCRA astronomers have made wide-field radio maps of the bright nearby H II regions Orion A and B. The observations have been made at two wavelengths: 90cm, where the central regions are highly opaque; and at 2.8cm, where the nebuale are fully transparent. These studies have yielded the most accurate estimates of the electron temperatures of these nebulae from radio continuum data alone.

An extensive survey of hydrogen recombination lines in the Galactic plane has been carried out by the RRI astronomers using ORT. Results include discovery of large low-density

envelopes around conventional H II regions. Radio recombination lines have been systematically observed by the RRI scientists over a wide range of frequencies (25MHz to 10GHz) from a variety of objects such as H II regions, cold interstellar clouds, the warm ionized interstellar medium, the galactic centre, nuclei of external galaxies, etc. These observations done with the ORT, the low-frequency array at Gauribidanur, the 43m and the 93m single-dish telescopes of the National Radio Astronomy Observatory, as well as the VLA, have been used to derive some of the properties of different ionized regions.

To study the properties of the ionized component of the interstellar medium, an extensive interplanetary scintillition survey of the Galactic plane was carried out by the NCRA scientists using the ORT. The absence of sources with components smaller than 0.5 arcsec in the Galactic central region indicates large interstellar scattering in these directions. A two-component model for the distribution of scattering plasma and an estimate for the scattering angle as a function of latitude were also derived from these observations.

A major research interest at IIA has been radiative transfer studies including computation of intensity and polarization line profiles in the spectra of planetary atmospheres; and studies of line formation in extended and moving atmospheres. Scientists from TIFR have proposed the idea of pressure dissociation in the context of stellar atmospheres and estimated its effect. TIFR scientists have discovered CO molecule in hot B supergiants and several Be stars. Cosmic ray excitation of the Lyman and Werner systems of the hydrogen molecules has been shown by the TIFR scientists to produce chemically significant levels of UV photon flux in dense clouds. Dynamical models of the formation of low-mass stars from interstellar clouds incorporating processes such as excitation, ionization, cooling and chemical reactions have been constructed by the TIFR scientists. Scientists from the Inter-University Centre for Astronomy and Astrophysics (IUCAA) have been working on models of stellar and primordial nucleosynthesis and their relationship to the observed abundances and the overall chemical evolution of the Galaxy. Theoretical studies of pulsars are being carried out at various centres including RRI.

Galaxies and cosmology

Improvements in techniques have made it possible to study other galaxies in depth.

A photographic study of 50 Sersic-Pastoriza galaxies was carried out at IIA using the Kavalur 1m reflector. Nuclear regions of these galaxies show bright substructure due to episodes of star formation. A classification scheme was suggested that reflects the intensity and evolutionary stage of the star burst. The nuclear components of sizes less than 1 kpc were

distinguished from circumnuclear components of mean size 1.5 kpc. The nucleus is often very red, and was indentified for the first time in NGC 2903 using high-resolution I-band images. The brightness of the nuclear and circumnuclear components in the barred galaxies in the sample has been correlated with the length of the bar indicating the role the bar plays in the supply of gas to the centre.

A survey of red stars in the direction of Large Magellanic Cloud (LMC) has been completed at IIA, using ultra-low resolution objective prism spectra taken at the 1m reflector. A majority of the stars are M giants and supergiants or carbon stars belonging to the LMC. BVR H α photometry has been carried out from VBO for 161 H II regions in nine galaxies. Specific model spectra have been constructed with a view to interpreting these observations. Comparison of the two reveals the following: (i) The stellar component experiences lesser amount of dust extinction compared to the gaseous components. There is also evidence for a significiant escape of ionizing photons from the brightest regions. Both these observations indicate a clumpy distribution of the gas. (ii) A majority of regions have undergone more than one burst of star fromation during the last 10 million years. (iii) About 10 solar masses of gas is converted into stars during each burst of stars formation. IIA astronomers in collaboration with scientists from TIFR and IUCAA have observed early - type galaxies that are members of small groups, selecting them for their radio or X-ray brightness. A majority of galaxies observed have shown evidence of gas and dust. Studies of surface brightness of galaxies in various colours; star forming regions in galaxies; and variability of QSOs and AGN are some of the programmes that are being pursued in the field of extragalactic research by scientists from IIA, IUCAA and TIFR.

Over a dozen extragalactic supernovae have been observed spectroscopically near light maximum from VBO and their spectral type and their expansion velocity determined. A few of these, notably SN 1987A in LMC and SN 1993J in M81, were monitored for longer periods. SN 1987A was a subluminous type II and exploded after the progenitor had made an excursion towards blue in the H-R diagram following a red supergiant phase. IIA astronomers have produced evidence indicating nitrogen enrichment in the surface layers. This implies CNO cycle processing in the progenitor. The velocity structure of the outer layers was measured for both these supernovae, and a distance estimate obtained for SN 1993J.

IIA astronomers have contributed to the International Active Galatic Nuclei Watch by monitoring NGC 3783 spectroscopically and photometrically. Search is also being made for intra-night optical variability in radio-quiet QSOs in order to constrain theoretical mechanisms for microvariability. Photometry has been performed on X-ray selected AGN. At IIA, the population synthesis technique has been applied to a few nearby galaxies using spectra obtained

at the European Southern Observatory, Chile. The age of the older population and the epoch of recent star formation were determined for the galaxy NGC 5128. Other projects at IIA using data obtained elsewhere include the study of stellar content of young star clusters in the LMC.

Numerical and analytical studies in galaxy dynamics have been carried out at Osmania University, IIA, RRI and TIFR. Analytical results on tidally interacting galaxies using impulse and adiabatic approximations have been obtained at Osmania. Numerical work at IIA has shown them to be in broad agreement with the N-body computer simulations in respect of merger velocities, energy transfer and merger times. Transfer of not only energy but also angular momentum in the case of tidal encounter between galaxies has been numerically investigated at IIA.

One of the major programmes carried out with the Ooty Radio Telescope (ORT) has been a lunar occultation survey along the moon's path in the sky. The survey yielded accurate positions and brightness profiles for about 1000 weak radio sources with resolutions of about one to 10 arcsec at 327MHz. Such high resolutions had not previously been attained for any large sample of weak sources. The positional accuracy was sufficient to make reliable optical identifications on the Palomar Sky Survey prints. The database was used to establish, for the first time, a correlation between the angular sizes of the radio sources and flux densities, which in turn led to the important conclusion on the evolution in physical sizes with cosmic epoch. A significant fallout of the occultation programme was the development of a new technique of deconvolution of occultation records. This resulted in a two-fold improvement in the resolution achievable in obtaining brightness distributions over the conventional methods. It was one of the first uses of the positivity constraint as an a priori information, which was later applied in the maximum entropy methods for deconvolving radio images obtained with aperture synthesis telescopes.

Another major programme undertaken with ORT has been the observation of interplanetary scintillations (IPS) in the intensity of distant radio sources. These scintillations are caused by electron-density irregularities in the interplanetary medium (solar wind). Such observations made at different solar elongations provided valuable information both on the properties of the medium and on fine structure (< 0.5 arcsec) in radio sources. Scintillation studies of hundreds of sources lead to the conclusion that in the case of a large number of powerful radio sources, a significant fraction of their flux density arises in compact (< 0.5 arcsec) hot spots in the outer lobes. More direct estimates of the angular sizes of hot spots in a sample of 3CR radio sources at large redshifts were subsequently obtained using VLBI techniques which showed that compact hot spots (sizes <0.15 arcsec) were fairly common in powerful radio galaxies and quasars.

Detailed radio images of a large number of quasars at the VLA were also used to show that there is no significant dependence of the sizes of the hot spots on either redshift or radio luminosity. The relative strength of the hot spot however appears to increase with radio luminosity.

That compact sources (with overall sizes < 10 kpc) constitute a significant fraction of the population with steep radio spectra was first recognized from high-resolution observations with the Westerbork Array of a complete sample from a 5GHz survey. Work by the NCRA scientists has shown that the fraction of such sources appears to increase rapidly with redshift, which could be related to an enhancement in the beam efficiency and to stronger confinement in a denser interstellar medium at earlier epochs.

Some of the earliest statistical tests to explore the possibility of a `unification scheme' in which the flat-spectrum core-dominated sources are the relativistically beamed counterparts of the lobe-dominated ones were carried out at NCRA. Several properties such as projected linear sizes, hot spot misalignments, redshift distributions, orientation of radio polarization vectors etc. were found to support the unification scheme. Evidence was also presented for an aspect dependence of the optical/UV continuum emission of quasars, which implied that all optical magnitude-limited samples of radio quasars were likely to be biased with regard to the orientation of their jet axes. It now appears that both radio galaxies and quasars should be included in an enlarged unified scheme in which they are all intrinsically similar, but objects with small viewing angles ($< 45^{\circ}$) are seen as quasars and those with larger viewing angles as radio galaxies.

The NCRA scientists have inferred hot spot velocites of about 0.1 to 0.25c in double radio sources on the assumption that the entire observed asymmetry is due to the fact that they are seen at different ages owing to light-travel-time effects. It has been recently shown that the closer of the two hot spots almost always lies on the same side of the nucleus in which the extended optical line emission has a higher surface brightness. This appears to provide the first direct evidence that lobe distance asymmetries could be largely intrinsic in nature.In quasars the misalignments of the hot spots on the two sides have been found not to depend on the epoch.

A three-year flux monitoring programme at 327MHz carried out using the Ooty Synthesis Radio Telescope (OSRT) has provided fresh support for an extrinsic origin (possibly due to refractive interstellar scintillations) of low-frequency variability in quasars. A superluminal microlensing model has been proposed to explain the phenomenon of ultra-rapid variations (with day-like timescales) at cm wavelengths. The bright pair 1830-21 of flat-spectrum radio components separated by just one arcsec was discovered serendipitously by NCRA scientists in the course of the Ooty Galactic Plane Survey, and has been interpreted as core of a distant radio

source being lensed by an intervening galaxy. Recent VLA and Merlin maps have revealed it to be a compact 'Einstein ring'. The giant radio galaxy 0503-28 with a size of 2.5Mpc, is the largest known radio source in the southern hemisphere, was discovered by the NCRA scientists independently from observations with the OSRT and using the Molonglo Synthesis Telescope in Australia. As part of an extensive study of clusters of galaxies, an ultra-steep spectrum radio source without any obvious optical counterpart was discovered in the cluster Abell 85 by the NCRA scientists.

The NCRA scientists have used OSRT to study the large scale structure of a number of nearby galaxies. A multifrequency study of the edge-on spiral galaxy NGC 4631 showed evidence of spectral steepening with distance from the disc of the galaxy. A number of Seyfert and Sersic-Pastoriza galaxies have been studied with high angular resolution using VLA and Merlin arrays to look for radio evidences of starbursts and collimated ejection from their active galactic nuclei. Several studies have been made by NCRA scientists and collaborators to determine the local and evolving radio luminosity functions and on possible explanations for the observed changes.Spectral measurements of the Ooty occultation sources, combined with several other datasets, have been used to establish a statistical relation between median radio spectral indices and flux densities of extragalactic sources found in metre-wavelength surveys. These studies have raised doubts about the long-held view that the average spectral index was steeper at earlier epochs.

The TIFR group is closely involved in two major programmes to optically identify and study high redshift galaxies from Molonglo and Ooty samples. These studies have already led to the discovery of about 25 radio galaxies at redshifts greater than two, including two at $z > 3$, which are among the most distant galaxies known in the universe. Observations with the ORT have allowed interesting upper limits to be placed on the H I mass of the clusters and superclusters at $z = 3.3$. As already noted, it would be possible to undertake much more sensitive searches for H I at even higher redshifts, using the Giant Metrewave Radio Telescope (GMRT). Using the Australia Telescope at a frequency of 8.7 GHz, scientists at NCRA and Australia have recently placed an upper limit of 2×10^{-5} on fluctuations in the cosmic microwave background radiation on an angular scale of about one arcmin. This is the most stringent upper limit to date on fluctuations on this scale.

It was shown by TIFR scientists that the Seyfert galaxy NGC 4945 is quite extended at all IRAS bands, while another Seyfert, Circinus galaxy, shows only central emission. It was also found that the extended emission from NGC4945 at 26K is cooler than the central emission at 39K.

Peer review system for funds has not operated as rigidly in India as in the west. This has resulted in some papers of the nonconformist kind appearing from India in reputed international journals. Thus it is still possible in the Indian institutions to do research on alternatives to the big bang cosmology or to question the cosmological hypothesis for quasar redshifts.

Space and high energy astrophysics

Strictly speaking, matter in this section should be distributed between the two preceeding sections. However, for the sake of convenience, results of X-ray and gamma ray observations have been grouped here.

In the early phase, the key objective of the hard X-ray astronomy programme at TIFR was a detailed study of spectral and temporal characteristics of known sources like Sco X-1, Cyg X-1, Her X-1, Cyg X-3, and sources towards the Galactic centre. Simultaneous hard X-ray and optical observations of ScoX-1 during 1968-72 showed that the X-ray intensity in the 20-40 keV range shows a positive correlation with the optical luminosity in the bright phase of Sco X-1. It was also concluded that a flare results from an increase in the total mass of the hot plasma but not its temperature. In 1984, a temperature of $kT = 6.5 \pm 0.9$keV was deduced from Sco X-1 X-ray spectra using a thermal bremsstrahlung model. In 1971, Cyg X-1 was shown by TIFR scientists to be one of the most chaotic and rapidly varying sources at all X-ray energies. A hard X-ray flare was reported for the first time (subsequently verified by the PRL group and others). The 1984 observations implied a Comptonized black-body spectrum with a plasma electron temperature $kT = 28 \pm 4$keV. No evidence was found for any kind of pulsed emission, thus ruling out an embedded pulsar in Sco X-1.

The star of 1973 was the binary Her X-1. Its spectral measurement was extended to 60keV. It was shown that the pulsed component was less than 10% of the total emission in hard X-rays. This result was later borne out by satellite measurements. It was also shown that the origin of the low and high energy X-rays must necessarily be the same. The source 4U1907+09 showed (in 1985) only marginal pulsations with a period of 432.70s in the 20-80keV interval. This result however needs to be confirmed. The 1984 observations of the X-ray pulsar GX1+4 seemed to imply a reversal of the spin-up of the embedded neutròn star.

Rocket-borne X-ray observations have been made in the 0.1 - 20 keV range of a number of objects: transient sources like Cen X-1, Cen X-2 and Cen X-3; binary sources like Sco X-1 and Cir X-1, supernova remnants, as well as the diffuse X-ray background. Balloon-borne observations in the energy range of 20-200 keV have been carried out for a number of sources including Her X-1 and Cyg X-1.

The first Indian satellite Aryabhata carried a payload consisting of X-ray telescopes in the medium energy range 2-20 keV and the hard range 20-150 keV. An X-ray sky monitor camera (designed and built in collaboration with TIFR) was placed on the Bhaskara I satellite. Work is on at ISRO for setting up an X-ray astronomy experiment (in collaboration with TIFR) for possible launch on the Indian Remote Sensing Satellite (IRS)-D2 mission. The experiment consists of four pointed-mode proportional counters operating in the energy range 2-20 keV, and two monitor proportional counters in the range 2-10 keV.

An experiment for studying celestial gamma-ray bursts was set up by ISRO aboard SROSS-C satellite launched on 20 May 1992. The experiment was aimed at measuring the temporal and spectral evolution in gamma ray bursts in the energy range 20 keV - 3 MeV. The experiment worked satisfactorily during the satellite's short life time of 54d. Another experiment for gamma-ray studies is a part of payload of SROSS - C2 launched on 4 May 1994 (see chapter 2). An experiment was carried out by TIFR scientists to measure the diffuse gamma-ray background in 0.2-4 MeV energy range. It was concluded that the emission is of extragalactic origin. The observed spectrum is well accounted for by a power law spectrum of index - 1.8 ±0.2. A series of balloons were flown during 1977-80 in collaboration with scientists from Moscow. It has been shown that in the case of the Seyfert galaxy 3C120, gamma-ray luminosity exceeds the X-ray luminosity by a factor of 100.

Scientists from TIFR and Bhabha Atomic Research Centre, Bombay (BARC) have studied high energy gamma rays using the atmospheric Cherenkov arrays at Pachmarhi and Gulmarg, and the air shower arrays at Kolar Gold Fields and Ooty. Highlight of results obtained during the past 10 years is that some objects like the Crab pulsar and Hercules X-1 are sporadic emitters of gamma rays. In 1987 pulsed gamma-ray emission was detected from the radio pulsar 0355+54, from Pachmarhi, in confirmation of theoretical predictions. That white divaifs, like neutron stars, could also produce pulsed emission was shown by Gulmarg observations of the cataclysmic variable AM Herculis. In various collaborative programmes,data from satellites have been analysed. In addition there have been related theoritical studies.

TIFR scientists have measured the low but finite fluxes of Li, Be and B in the primary cosmic radiation allowing one to deduce the path lengths of primary cosmic rays. Measurements were made of the electron and positron energy spectra in primary cosmic rays up to a few tens of GeV energies, with a view to understanding some aspects of acceleration and propagation of primary cosmic rays. A qualitative estimate has been made of the charge composition of priamry cosmic rays in the energy range 5×10^{14} to 5×10^{16} eV by simultaneous observations on electrons at the suface and on muons underground at the Kolar Gold Fields in extensive air shower experiments.

General relativity and gravitation

Work in the 1940s and 150s included well known contributions by P.C.Vaidya (1944) and A.K.Raychandhuri (1955). By and large, work in general relativity in India has involved solving differential equations to find exact solutions of Einstein's equations and studying some geometrical aspects of the theory. This work is being carried out at various centres including colleges and universities. There have come important contributions to gravitation theory and cosmology, including studies of black holes.

The perturbations of black holes in normal as well as in quasi-normal modes have been studied at RRI, IUCAA and IIA. The scalar perturbations of spherically symmetric black hole solutions in theories with quadratic Gauss-Bonnet corrections have also been investigated. Charged particle trajectories around black holes in vacuum as well as in magnetic fields have been studied by several authors at PRL, IUCAA, Indore and Ravishankar Universities. It has been shown at IUCAA that the criterion for corotation should be redefined relative to a locally nonrotating observer so as to avoid conflict with the second law of black hole physics and the conservation of energy. An attempt was made at TIFR to define a black hole in an expanding universe. Workers at IUCAA and the University of Poona have considered the effect of rotation and magnetic field on the shape of the event horizon of a black hole. In the spirit of the Gauss theorem, the gravitational charge of a rotating black hole has been defined and applied to a black hole in a magnetic field.

Modem techniques have been employed at TIFR to study the type of matter distribution in the physical universe that is allowed by general considerations of global hyperbolicity and causality. Quantum effects on space-time singularities of general globally hyperbolic space-times have been investigated at TIFR, leading to the conclusion that some non-singular states are also probable. Linearization stability of the solutions of Einstein's equations has been demonstrated by workers from TIFR and Bhavnagar and Nagpur Universities. Works on the extent of validity of the cosmic censorship hypothesis is going on at TIFR and Aligarh Muslim University.

Scientists at IUCAA and TIFR have done pioneering work in the area of quantum gravity by quantizing the conformal degree of freedom and studying its cosmological effects. In this restricted treatment it is shown that quantum effects will force the universe to avoid the big bang singularity. Quantum field theory in curved space-time, semiclassical calculations in space-times of interest and the application of results from particle theory to cosmology including inflation have been considered by several workers.

The existence and relevance of dark matter in astrophysics and cosmology was first published in 1972 in a collaborative study from TIFR. The proposal was that weakly interacting particles with a finite rest mass (neutrinos) left over from the big bang would constitute a gravitating background of invisible matter; these would trigger the formation of galaxies and would explain the discrepancy in the virial masses of galactic systems . In the mid 1980s, there was a spurt of activity on this topic and several workers considered dark matter of various types. Cosmological implications of cosmic strings are being considered at TIFR and IUCAA. A major effort on data analysis of gravitational waves in various detecting systems is currently under way at IUCAA. The signal-to-noise analysis including the photon counting noise and thermal noise has been made for an array of five, four and three detectors.

The properties of a thin accretion disc around a rotating black hole in a magnetic field have been considered at PRL and Ravishankar University. The magnetohydrodynamics around rotating black holes has been extensively studied at TIFR. By taking into account the presence of magnetic field around a rotating black hole, scientists at IUCAA have revived the Penrose process of energy extraction as a viable mechanism for powering the central engine in active galactic nuclei and quasars . The capture of gravitational neutrinos has been extensively studied at RRI. Scientists at IIA and Delhi University have studied gravitational red shift and spectral line broadening of radiation from a rapidly rotating pulsar by taking the Kerr metric to represent the pulsar. A suggestion to consider white holes as a source of high energy radiation was also studied at TIFR, IIA and Poona University in the 1970s. The gravitational bending of a light ray gives rise to the astrophysically interesting phenomena of gravitational lensing and superluminal separation of VLBI components in quasars. Considerable work has been done in this important area at TIFR and RRI.

4

Promotional activities

There is now in the country a sizeable number of professional astronomers and space scientists. A number of learned societies coordinate their activities at various levels. Activity at the amateur level is also on the rise.

National Academies

International relations in astronomy are overseen by the Indian National Science Academy through its National Committee for the International Astronomical Union. Research projects on history of astronomy can be funded by the academy through its Indian National Commission for the History of Science, which also publishes the *Indian Journal of History of Science*. Indian Academy of Sciences, Bangalore, brings out a quarterly *Journal of Astrophysics and Astronomy* as a vehicle for publication of results in modern astronomy.

Indian Astronomical Society

Meghnad Saha's idea of forming an Indian Astronomical Society could take shape only a few years after his death in 1956. The Society was registered on 24 September 1959. It was inaugurated in December 1960 under the chairmanship of A.C.Banerjee, but for some reason the Society's work came to a halt by 1963. It was revived in 1974. The first elected council was formed in 1977 with N.C.Lahiri as President and B.N.Basu as Secretary. Since 1986, the Society has an office in the Department of Applied Mathematics, Calcutta University. The Society started the publication of its journal *Akash* in 1980. The name was changed to *Mahavisva* in 1982. As the registration of the journal was delayed for several years, a new series was started with Volume 1 in 1988. The Society holds national and international seminars and symposia. It also conducts summer and winter schools on basic astrophysics, and arranges popular lectures by eminent Indian and foreign scientists.

Astronomical Society of India

In 1970-71, a questionnaire was sent to about 150 scientists to seek their view on the need for setting up an all-India astronomy forum. About 100 of them responded, all except two supporting the idea. Accordingly, the Astronomical Society of India enrolled its first member on 25 October 1972; another 20 joined on 14 November. The Society was formally registered on 19 January 1974, with its office in the Astronomy Department, Osmania University, Hyderabad. The first meeting was held in March 1974, when its memorandum and bye-laws were passed. The first President and Secretary were M.K.V Bappu and K.D. Abhyankar. The Society has on its rolls 284 regular members, including 208 life members, 88 associate members, seven institutional members, and one donor member. Honorary fellowship has been conferred on S.Chandrasekhar, (late) Z.Kopal, (late) D.S.Kothari, R.Hanbury Brown, and A.K.Raychaudhuri.

The Society has been publishing a quarterly journal, *Bulletin of the Astronomical Society of India*, since 1973, and exchanging it with a number of corresponding societies in Australia, Britain, Germany, countries of the former Soviet Union, and the U.S.A. The Society offers an award for the best paper published in the Bulletin by authors below 35.

The Society meets about twice in three years. The programme usually consists of invited talks, contributed papers, special sessions on topics of current interest, and popular lectures. Very often, a seminar or a symposium is held in conjunction with the scientific meeting. A limited number of travel grants are offered to enable research workers to present their results at the meetings. The Society also runs a programme by which interested amateurs, mostly school and college students, are sponsored for visits to astronomical centres. The Society has instituted an international award, called Vainu Bappu Memorial Award, after its first President, to be given to astronomers (normally below 35) who have made exceptional contribution to any branch of astronomical sciences. The medallists include Yasuko Fukui (Nagoya University, 1986), Shrinivas R. Kulkarni (California Institute of Technology, 1988), and George P.Efstathiou (University of Oxford, 1988).

Indian Association for General Relativity and Gravitation

In February 1969, Indian relativists met in Ahmedabad to felicitate their doyen, V.V.Narlikar, on his 60th birthday. It was decided at the meeting to set up the Indian Association for General Relativity and Gravitation (IAGRG) with V.V.Narlikar as the President and J.Krishna Rao as the Secretary. IAGRG has a membership of about 180. It brings out a news bulletin called *Gurutva*, and holds scientific meetings at an average interval of a year and a half. IAGRG

manages the Vaidya-Raychaudhuri Endowment Fund established in 1986. Since 1989, the Fund has been used to hold a Vaidya-Raychaudhuri Lecture by a distinguished scientist, at every IAGRG meeting.

In the early 1980s, at the initiative of some of the Association members, the University Grants Commission formed a National Coordinating Committee on Relativity and Cosmology to foster the growth of these subjects in the University departments of physics and mathematics. The Committee coordinated activities in this field for the Commission, including orientation programmes for teachers and advanced-level workshops for research workers. Now the Committee has been dissolvewd and its activities entrusted to the IUCAA.

IAGRG co-sponsored the Einstein Centenary Conference in 1979 at the Physical Research Laboratory, Ahmedabad. In the mid 80s, the Association started a four-yearly series of International Conferences on Gravitation and Cosmology. So far the conferences have been held at Goa (1987) and Ahmedabad (1991). The 1995 conference will be held at the Inter-University Centre for Astronomy and Astrophysics, Pune.

Amateur and popular astronomy

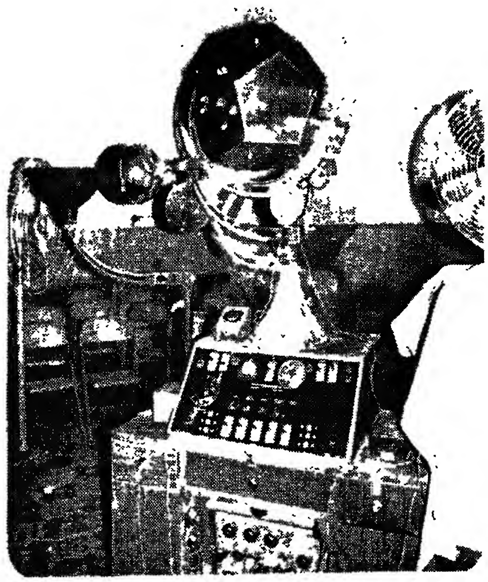
The 'old ever-young' science of astronomy commands an enthusiastic band of followers at the popular as well as amateur level. According to a rough estimate there are about 400 telescopes of about 10-15cm aperture in the hands of individuals and public institutions. There are about 40 active astronomy clubs in the country, some of which have been in existence for as many as 50 years, e.g., the Jyotirvidya Parisamstha, Pune. Many bring out informative newsletters, based on material published elsewhere. In addition, a fairly large number of popular books are written in Indian languages, especially Bengali and Marathi. Many of these books are the only authentic source of astronomical information for their readers.

Expectedly, there is a great demand for telescopes whenever comets and eclipses hit the news headlines. Most astronomy buffs are content with viewing the celestial object with their eyes; only a handful seek to preserve the image on a photographic film. Most amateur work has tended to be picture postcard type rather than research publication type. Conscientious efforts are being made by astronomical research centres to motivate amateur astronomers, especially students, to make reliable observations and communicate their results to professional channels. Amateur organizations are being offered support in terms of funds, equipment and resource personnel by various research institutions. A number of workshops on making small telescopes have been held under professional auspices, although lack of easy availability of good quality

glass blanks remains a problem. IUCAA has already created a cell for promoting amateur and popular astronomy and organized pedagogical and do-it-yourself workshops for amateurs and teachers of astronomy.

Initial steps have been taken to form a National Federation of Amateur Astronomers. Future plans for amateurs aim at introducing them to measurement astronomy. A number of schemes suggest themselves: making a variety of project-oriented photometers for use by amateur astronomers; development of low-cost automated drives for small telescopes; making available user-friendly reference material at low cost; and providing a refereed channel for publication of their results.

Popularization of astronomy takes place at various levels: print and electronic media, efforts by professional institutions, and planetariums. The government of India organizes science exhibitions all over the country, in which most institutions participate. Every year, 28 February (the date Raman discovered his effect) is celebrated as the National Science Day, when all scientific institutions keep open house. Observatories at Kavalur, Kodaikanal, and Naini Tal have earmarked small telescopes for use by visitors. Indian Institute of Astrophysics has produced two video films, on the 1980 solar eclipse and on Kavalur and Kodaikanal Observatories. It also video-recorded, in 1989, an interview with Prof.S.Chandrasekhar. India Meteorological Depart-



23. The planetarium at New English School, Pune. Set up in 1954, it is the oldest in the country.

ment's Positional Astronomy Centre, Calcutta, as part of its official duties, makes available sky charts and almanacs at a nominal price.

There are at present 30 planetariums in the country. The first planetarium in India was opened as early as 1954 in the New English School, Pune. Called Kusumbai Motichand planetarium, it was supplied by Spitz Laboratories, Philadelphia, U.S.A., at a total cost of Rs 35000. It owes its installation to the creative urge of an architect. The plan for the new school building included a 30 foot diameter, three-storey high dome, as a roof for the central hall. Given the dome, it was natural to think of a planetarium which became a reality thanks to a generous donation of Rs. 50000 by Motichand Shah in memory of his wife.

The next planetarium in India was the Birla planetarium at Calcutta set up in 1962. It was followed by Sardar (Vallabhbhai) Patel Planetarium at Baroda (1976) and Nehru Planetarium, Bombay- Worli (1976), Jawahar Planetarium, Allahabad (1980), Nehru Planetarium, New Delhi (1984). Other cities with planetariums are Bangalore, Bhubaneswar, Bombay-Powai,Calicut, Gorakhpur, Guwahati, Hyderabad, Jaipur,Lucknow, Ludhiana, Madras, Manipal, Muzaffarpur, Nagpur ,Patna, Porbander, Puttaparthi, Rajkot, Salem, Srinagar, Surat, Thiruvananthapuram, Vijayawada, and Warangal.(A few of these are not yet open to public.) Many planetariums in India are named after Jawaharlal Nehru, whose *Glimpses of World History* quotes [Sir] James Jeans on the expansion of the universe. His call for inculcation of 'scientific temper' constitutes the main point on the planetarium agenda. Planetariums are in general well equipped with the tools of the trade: models, graphics and software. They attract visitors from all age groups, but school children are specially targetted. There are introductory classes in astronomy, public lectures, and quiz and essay competitions for them.

Popularizing astronomy without trivializing it and conveying the rigour of science without intimidating the audience remain a challenging task.

Directory of addresses

Astronomical Society of India
C/o Department of Astronomy
Osmania University, Hyderabad 500007
Phone (40) 868951

Decameter-wave Radio Telescope
(Raman Research Institute)
(Indian Institute of Astrophysics)
Gauribidanur 561210, Kolar Dist, Karnataka
Phone (8155) 8625

Department of Astronomy
Osmania University, Hyderabad 500007
Phone (40) 868951

Department of Astronomy & Space Sciences
Punjabi University, Patiala 147002, Punjab
Phone (175) 822161 extn 6301.
Telex 394 219 PUP IN

Gravitation Experiment Laboratory
(Tata Institute of Fundamental Research)
BARC Seismic Array Station
Gauribidanur - Hosur 561208
Kolar Dist, Karnataka
Phone (8155) 2262

High Energy Gamma Ray Observatory
(Tata Institute of Fundamental Research)
Amrak Bhavan, Pachmarhi 461881
Madhya Pradesh
Phone 2113 (via Jabalpur or Bhopal)

Indian Academy of Sciences
C.V.Raman Avenue, Post Box 8005,
Sadashivanagar, Bangalore 560080
Phone (80) 3342546, 3344592. Fax (80) 3346094.
Telex 845 2178 ACAD IN

Indian Astronomical Society
C/o Department of Applied Mathematics
Calcutta University
92 Acharya Prafulla Chandra Road
Calcutta 700009

Indian Institute of Astrophysics
Sarjapur Road, Koramangala, Bangalore 560034
Phone (80) 5530672, 5530583. Fax (80) 5534043, 5534019
Telex 845 2763 IIAB IN. E-mail root@iiap.ernet.in

Indian National Science Academy
Bahadur Shah Zafar Marg, New Delhi 110002
Phone (11) 3313153, 3312450. Fax (11) 3716648.
Telex 31 61835 INSA IN. E-mail xxxx!vikram!insa!root

Inter-University Centre for Astronomy & Astrophysics
Post Bag 4, Ganeshkhind, Pune 411007
Phone (212) 336415, 336416. Fax (212) 335760.
Telex 145 658 GMRT IN. E-mail root@iucaa.ernet.in

ISRO Satellite Centre
Vimanapura, Bangalore 560017
Phone (80) 5566251. Fax (80) 5567621, 5567544.
Telex 845 2325. ISACIN. E-mail root@isro.ernet.in

Joint Astronomy Programme
Department of Physics, Indian Institute of Science, Bangalore 560012
Phone (80) 3344411. Fax (80) 3341683. Telex 845 8349

Kodaikanal Observatory
(Indian Institute of Astrophysics)
Kodaikanal 624103, Tamil Nadu
Phone (4542) 217, 643

Mauritius Radio Telescope Project
Faculty of Science,
University of Mauritius
Reduit, Mauritius.
Phone (230) 4237804, 4541041. Fax (230) 4549642
Telex 966 4621 UNIM IW. E-mail root @ f1. n726.z5. fidonet.org

National Academy of Sciences, India
5, Lajpatrai Road, Allahabad 211002
Phone (532) 641183, 64022

National Centre for Radio Astrophysics
(Tata Institute of Fundamental Research)
Post Bag 3, Ganeshkhind, Pune 411007
Phone (212) 333384, 336111. Fax (212) 345149
Telex 145 7658 GMRT IN. E-mail root@gmrt.ernet.in

Nuclear Research Laboratory
(Bhabha Atomic Research Centre)
Trombay, Bombay 400085
Phone (22) 5564225. Fax (22) 5560750, 5560534
Telex 116 1017, 116 1022 BARC IN.
E - mail root@ magnum. barc t1.ernet.in

Physical Research Laboratory
Navrangpura, Ahmedabad 380009
Phone (79) 462129. Fax (79) 460502.
Telex 121 6397 PRL IN. E-mail root@prl.ernet.in

Positional Astronomy Centre
(India Meteorological Department)
P-546 Block N, 1st floor
New Alipore, Calcutta 700053
Phone (33) 4780321, 4783541

Raman Research Institute
C.V.Raman Avenue, Sadashivanagar, Bangalore 560080
Phone (80) 3340122. Fax (80) 3340492.
Telex 845 2671 RRI IN. E-mail root@rri.ernet.in

Radio Astronomy Centre
(Tata Institute of Fundamental Research)
Post Box 8, Udhagamandalam 643001, Tamil Nadu
Phone (423) 2032, 4049. Fax (423) 2588. Telex 850 4208 RAC IN

Tata Institute of Fundamental Research
Homi Bhabha Road, Colaba, Bombay 400005
Phone (22) 2152971, 2152311. Fax (22) 2152110.
Telex 118 3009 TIFR IN. E-mail root@tifrvax.bitnet

Udaipur Solar Observatory
11 Vidya Marg, Udaipur 313001,
Phone (294) 60626, 60427. Telex 335 223 USO IN
E-mail uso@prl.ernet.in

Uttar Pradesh State Observatory
Manora Peak, Naini Tal 263 129,
Phone (5942) 2136, 2583

Vainu Bappu Observatory
(Indian Institute of Astrophysics)
Kavalur 635701, North Arcot Ambedkar Dist, Tamil Nadu
Phone 222, 255 (via Vaniyambadi)

(This is a partial list of organisations interested in the advancement of astronomy and astrophysics. It is a matter of satisfaction that the list is steadily becoming longer.)

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